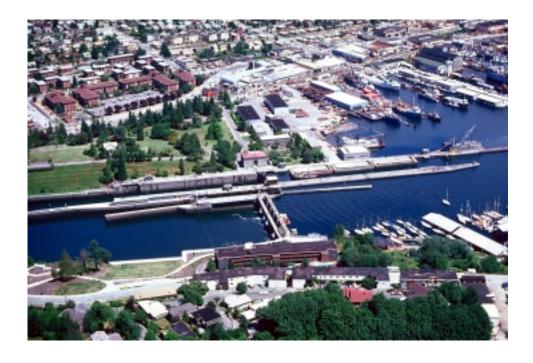


FINAL REPORT

PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Second Year (2001) Pilot Study Results

U.S. Army Corps of Engineers, Seattle District Lake Washington General Ecosystem Restoration General Investigation Study

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PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Second Year (2001) Pilot Study Results

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ABSTRACT

This second year pilot study continued the evaluation of the feasibility of using Passive Integrated Transponder (PIT) tag technology to monitor smolt migration and survival characteristics as they pass through the Lake Washington Ship Canal (LWSC) system, including the Hiram M. Chittenden Locks (Locks). Four smolt flumes and PIT tag detection devices (tunnel readers) were installed over the spillway dam of the Locks to monitor outmigration during the spring of 2001. Juvenile chinook, coho, and sockeye salmon were captured, tagged and released at two locations in the LWSC, and in the lower reaches of the Cedar River and Bear Creek. A few steelhead juveniles were also captured, tagged, and released. Hatchery-reared chinook were tagged, held, and released at the Issaquah Creek Hatchery and the University of Washington Hatchery. Calibration tests were performed using tagged hatchery chinook juveniles to evaluate the detection efficiency of the tunnel readers. Samples of fish captured by purse seining in the large lock and by beach seining in saltwater areas below the Locks were interrogated using hand-held detectors for PIT tagged fish. Problems that were encountered included computer data storage failure, equipment failure involving hand held readers in the lock and beach seining, structural features of the flumes reducing the detection efficiency of the tunnel readers, and the absence of complete coverage of PIT tagged fish passing the Locks through other routes. Nevertheless, the data provided valuable, detailed biological information for a second, consecutive year on migration, passage, and estuarine behavior of salmon smolts originating from different parts of the Lake Washington basin and transitioning to adult life in saltwater. The data included seasonal and diurnal migration and passage timing, passage routes through the Locks, and time to transition to saltwater. Passage rates were compared with flume discharge with the goal of determining optimal water allocation to the flumes. The data were also used to evaluate survival for different portions of the migration route, although the precision of the estimates was poor because of variable detection rates at the Locks on both a daily and seasonal basis, and low detection rates below the Locks. This information can be used for shaping spill timing and volume requirements at the Locks, and for evaluating causal mechanisms of decline. Study implications and improvements are suggested.

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Reviewers of the draft report include: Fred Goetz, Doug Houck, Bob Pfeifer, Keith Kurko, and Eric Bixler. Their comments helped improve the final report.

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1. INTRODUCTION

The Hiram M. Chittenden Locks (Locks; also known as the Ballard Locks) were constructed by the Seattle District, U.S. Army Corps of Engineers (USACE) as part of the Lake Washington Ship Canal (LWSC) project between 1911 and 1916 to provide for navigation between Lake Washington and Puget Sound (Figure 1-1). The LWSC is approximately 14 km (8.6 miles) long and lies entirely within the boundaries of the city of Seattle. The project was authorized by Public Law 61-264, River and Harbor Act of 25 June 1910, in the First Session of the 60th Congress in accordance with a plan set forth in House Document 953. The Montlake Cut, which extends between Lake Washington and Lake Union, was the final link in the route and was completed in 1917. Official dedication of the Locks project occurred on July 4, 1917. Other related activities that occurred around the same time included closure of the historic outflow of Lake Washington into the Black River in 1912 and concomitant rerouting of the Cedar River into the lake. Although the Locks have since undergone several structural modifications and improvements including construction of a saltwater intrusion barrier in 1966 and a new fish ladder in 1976, the entire LWSC project has effectively influenced anadromous fish passage and migration from the time they were constructed through to the present day.

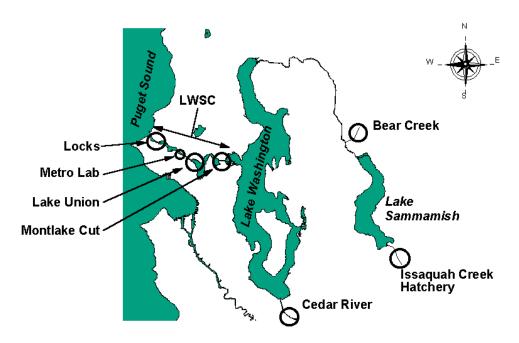


Figure 1-1. Locations of the Lake Washington Ship Canal (LWSC), Hiram M. Chittenden Locks, and PIT-tagged fish releases in the Lake Washington basin.

The Washington Department of Fish and Wildlife (WFDW) and Muckleshoot Indian Tribe (MIT) initiated field research in 1994, in cooperation with the Environmental Resources Section of the Seattle District, regarding the effects of operation of the Locks on the survival and general well-being of anadromous salmonids utilizing the Lake Washington watershed for various parts of their life-cycle. Issues raised in the studies have included successful downstream passage of juvenile and adult outmigrants, loss of estuarine habitat and the effects of a relatively sudden freshwater-saltwater transition, intrusion of saltwater into Lake Washington, and upstream passage of adult migrants. These and other concerns are particularly germane now in light of recent listings under the federal Endangered Species Act (ESA) of 1973 of Puget Sound chinook salmon (Oncorhynchus tshawytscha) and bull trout (Salvelinus confluentus), and potential listing of coho salmon (O. kisutch). It is important that the influence of the LWSC project on salmonid survival and health be fully understood so that appropriate measures can be developed and enacted that minimize or eliminate adverse effects. This document details the results from the second year of activities under a study that was designed to evaluate those effects using Passive Integrated Transponder (PIT) tag technology (Prentice et al. 1990a, b, c). The study is part of the greater Lake Washington General Ecosystem Restoration General Investigation (LWGI) Study being conducted by the Seattle District of the USACE.

1.1 PHYSICAL LAYOUT, FEATURES, AND OPERATION OF THE LOCKS

The Locks consist of a large and small lock on the north side, a fish ladder on the south side, and a 71.6 m (235') long concrete gravity spillway dam extending between the small lock and the ladder (Figure 1-2). There is also a saltwater return system that consists of a drain leading to below the spillway dam and a pipe that runs along the bottom of the LWSC to the fish ladder. The pipe discharge is distributed to a number of steps where it mixes with the freshwater entering the head of the ladder.

The large lock is 24.4 m (80') wide and can accommodate ships with drafts up to 9.1 m (30'). It consists of three operating gates that divide the lock into two chambers, two 4.3 m (14') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water into the lock to fill it, filling valves, and dewatering facilities. During normal operations, either one or both chambers are used depending on the size and number of ships passing through the facility. The valves can be used to vary the rate at which the lock is filled. A saltwater barrier is located at the upstream end of the lock and can be raised to reduce the volume of saltwater intruding into the LWSC when the upper gate is opened. Relatively strong density currents can

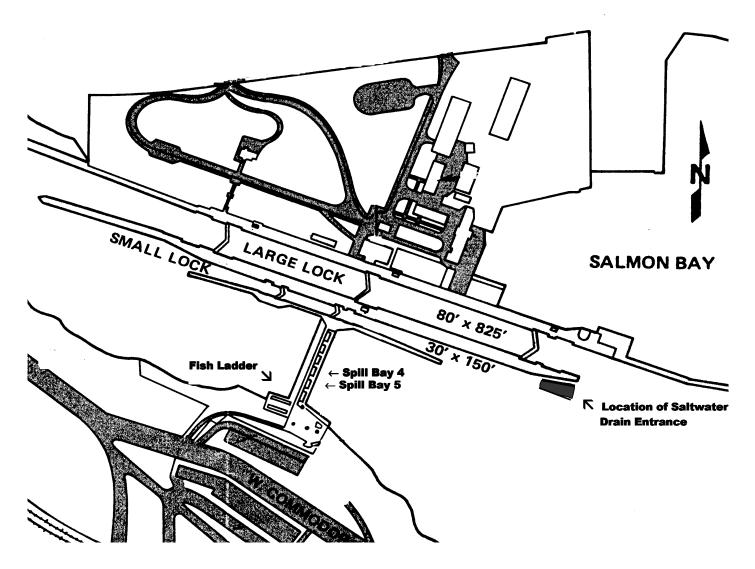


Figure 1-2. Plan view of the Hiram M. Chittenden Locks showing major structural features and location of tunnel readers in spill bays 4 and 5.

occur within the lock when the gate is opened, as surface freshwater enters the lock to replace the denser saltwater flowing out into the LWSC.

The small lock is 9.1 m (30') wide and can accommodate smaller boats with drafts up to 4.9 m (16'). It consists of two operating gates, two 1.8 m (6') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water into the lock to fill it, filling valves, and dewatering facilities. The valves can be used to vary the rate at which the lock is filled.

Saltwater intrusion is an important concern, particular with respect to managing water quality of Lake Washington and Lake Union, because of the concern that the resulting density stratification and water quality attributes of the lakes could transform their deeper areas into sterile, anaerobic waters. The Washington Department of Ecology has correspondingly set water quality standards, where the salinity in the LWSC at the University Bridge may not exceed 1 $^{\circ}$ /_{oo} (parts per thousand, ppt) at any point in the water column. The Locks are therefore managed to minimize intrusion as much as possible, which occurs with each lockage when a denser, more saline layer flows upstream under the less dense freshwater in the form of a density (or, gravity) current. The large lock is associated with approximately 25 times more saltwater intruding per lockage than the small lock, but the small lock is conversely used more frequently. A hinged barrier on the large lock bottom partly retards saltwater intrusion, but the main line of defense is the saltwater drain located immediately upstream. The saltwater drain has a discharge capacity of 300 cfs and returns water downstream.

The spillway dam consists of six bays that are numbered sequentially as numbers 1 through 6, from North to South. Each bay is 9.8 m (32') wide and controlled by a 3.8 m (12.5') radius tainter gate that is driven by an independent electric motor. The spillway has a design head of 2.3 m (7.4'), a crest elevation of 4.2 m (13.75'), an ogee shape, and is capable of discharging up to 515 m³/s (18,200 cfs) at the maximum regulated Lake Washington elevation of 6.7 m (22'). Beginning in May 2000, four seasonal smolt passage flumes (smolt flumes) have been installed in bays 4 and 5 with the goal of passing downstream migrating juvenile salmonids by the Locks (the flumes will be installed in April in each following year). These flumes replaced a prototype 'smolt slide' that was installed initially in 1995 for the same purpose of passing smolts downstream of the Locks.

The Locks regulate the elevation of the water surface of Salmon Bay, Lake Union, and Lake Washington. Project authorization documents specify the normal operating levels to be between

6.1 m (20') and 6.7 m (22') above the USACE Project Datum. The Project Datum, established on 1 January 1919, is 2.08 m (6.82') below the National Geodetic Vertical Datum (NGVD) and 0.17 m (0.57') below the Seattle mean lower low water (MLLW) elevation. In constructing the LWSC project, the level of Lake Washington was lowered about 2.7 m (9') from its historic elevation. The storage between the 6.1 m and 6.7 m levels has been used historically to augment LWSC inflows for use in operating the Locks, the saltwater return system, and the fish ladder facility. More recently, the storage is also used to provide flows to the smolt flumes during the spring outmigration period.

There are four seasonal periods of operation: the winter holding period (low pool), the spring refill period, the summer conservation holding period (full pool), and the fall drawdown period. The lake elevation is maintained at the minimum level (6.1 m) during winter months to allow for maintenance on docks, walls, etc. by businesses and lakeside residents, minimize wave and erosion damage during winter storms, and provide storage space for high inflows during flood events. The spring refill period begins February 15 and continues until generally the first week in May when the lake reaches 6.66 m (21.85'), which is slightly less than the full pool level (6.7 m; levels can reach this depending on water availability). The spillway gates (and also now the flumes when appropriate) are operated to keep the lake elevation near its maximum authorized normal level of 6.7 m. The upper limit is dictated by physical design restrictions of the spillway gates and requirements of lake-associated infrastructure. Water demands of the Locks, the saltwater drain, the fish ladder, and the flumes result in the lake elevation gradually lowering, beginning in late June to late July depending on water availability. The Water Conservation Plan that is in effect at the Locks attempts to maintain lake levels at or above the 6.1 m level as much as possible (70% historic reliability level). It is not always possible, however, to maintain this elevation during abnormally low water years and when higher than usual saltwater intrusion associated with lock openings requires additional flushing.

1.2 CONTEXT AND PURPOSE OF THE PIT TAG STUDY

The PIT tag study is part of the greater LWGI study, which was initiated in July 1999. In addition to the USACE, co-sponsors of the LWGI study include the City of Seattle and King County. Other participants in the study include WDFW, MIT, the National Marine Fisheries Service (NMFS), the USACE Waterways Experiment Station (WES), Biomark Inc., and BioSonics, Inc. The Locks were previously the focus of four years of baseline studies between 1995 and 1998 that pertained to fish passage conditions and behavior of migratory juvenile chinook salmon and other migratory salmonid species. These studies have been a cooperative effort between several resource agencies, including the WDFW, MIT, WES and the USACE.

The purpose of the LWGI study is to evaluate various projects that may contribute to (i) restoration of ecological processes or functions within the Lake Washington basin, including improving fish passage at the Locks, and (ii) water conservation by the LWSC project to provide additional water for fish passage through the Locks. The LWGI study consists of environmental monitoring activities occurring over 2000, 2001, and 2002 that complement post-flume construction monitoring performed as part of the Lake Washington Ship Canal Smolt Passage, Section 1135 Restoration Project (USACE 1999). Monitoring activities are targeted at evaluating both juvenile and adult salmon passage at the Locks. Juvenile monitoring activities include: PIT tagging and detection at various locations including the Locks; beach seining in Lake Washington and in the saltwater environs of the Locks; studying food habits of juvenile chinook salmon in Lake Washington and of piscine predators below the Locks; monitoring of fish entrainment into the large lock culverts and subsequent injury and survival using split beam hydroacoustics and purse seine sampling; monitoring of entrainment into the saltwater drain using split-beam hydroacoustics, and monitoring of passage during spill over spillbay gate no. 2 using single beam hydroacoustics.

Monitoring objectives for the juvenile studies in the LWSC include:

- Developing smolt survival (mortality) estimates for each salmon species migrating through the LWSC and Locks;
- Identifying major limiting factors contributing to smolt mortality;
- Monitor fish passage through major outlets at the Locks (including studies under the LWSC Section 1135 Project) four new smolt passage flumes, the large lock culvert intakes, the saltwater drain, and spillway gates; and
- Identifying and assessing possible structural and non-structural restoration measures that may improve smolt survival.

Results presented in this report address the following objectives common to both the first and second year PIT tag assessment components of the LWGI study:

 Evaluating the efficacy of PIT tagging as a means for estimating survival of wild and hatchery fish as they migrate through different portions of the Lake Washington and LWSC system;

- Evaluating the efficacy of PIT tagging naturally-reared smolts in tributaries to Lake Washington and in the LWSC;
- Assessing whether hatchery-reared chinook salmon are a good model for evaluating the effects of the LWSC project on naturally-reared fish; and
- Evaluate smolt mortality estimates for salmon species migrating through the Locks, and
 using the estimates to evaluate migration pathways, passage structures, and the effects of
 water conservation.

In addition to survival estimates, measures that indicate the success of meeting these primary objectives include obtaining useful information on migration and passage behavior and survival estimates. The resulting data can be used in evaluations of alternative operations at the Locks and other restoration measures, and either directly or indirectly address the following specific restoration objectives of the LWSC Section 1135 project:

- Increasing smolt passage numbers over the spillway;
- Minimizing smolt entrainment into the large lock filling culverts;
- Minimizing smolt injury during passage through the large lock culverts;
- Evaluating the effects of the Locks on smolts during their estuarine phase; and
- Minimizing injury and mortality to chinook salmon in conformance with ESA listing of Puget Sound chinook.

2. METHODS

The methods used in this study reflect more than basic needs for evaluating the feasibility of PIT tagging in the Lake Washington system. This study was also designed to yield first-order estimates of survival over various portions of the migration route and details about migration characteristics related to factors within and outside of the control of water management operations at the Locks. The study design generally involved tagging and release of wild and hatchery juvenile chinook salmon at various locations in the watershed, and detecting them at the Locks and downstream. Study design and methods are described below.

2.1 PIT TAG TECHNOLOGY

PIT tags are small, unobtrusive electronic devices that are implanted in the abdominal cavity of fish. The tags used in this study were 134.2 kHz Destron-Fearing TX1400BE, 14 character tags. The tags do not appear to influence fish behavior or survival significantly when inserted properly (Prentice et al. 1990c). Tagging mortalities generally do not exceed 1%-2% based on experience in the Columbia River (S. Achord, NMFS, personal communication). The tags consist of an antenna coil of coated copper wire that is connected to an integrated circuit chip, all encased in a glass tube that is approximately 12 mm long and 2.1 mm in diameter (Figure 2-1). The device works on the principle of induction of current in a coil as it passes through an electromagnetic field. As the tag passes through the field created by a detection device, the current that is induced in the coil powers the chip, which subsequently transmits a unique tag identification number code through the coil. The tag signal is received by a coil loop of the detection device and is decoded. Each PIT tag in this study had 10 unique characters that distinguished it from approximately 34 x 10⁹ other possible code combinations (Prentice et al. 1990a, b, c).

The distance at which a PIT tag may be detected is relatively short because of power generation and dissipation concerns in a water medium. Consequently, the fish must either be made to pass through the coil of a detection apparatus that is fixed in position at a structure where passage can be controlled, or the tagged fish must be captured in the field and held near a portable ('handheld') detector. In this study, four fixed detectors ('tunnel readers') were custom fabricated and installed in spillway bays 4 and 5 at the Locks, and hand-held detectors were used in the field for detecting tagged fish that were caught during various seining operations.

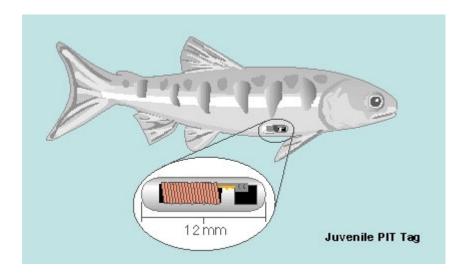


Figure 2-1. Schematic of a Passive Integrated Transponder (PIT) tag inside a juvenile salmonid.

2.2 INSTALLATION AND MONITORING OF TUNNEL READERS AT THE LOCKS

Spillway bays 4 and 5 were converted into smolt passage facilities by raising the radial gates and installing bulkheads with adjustable gates that controlled free surface water flow into four flumes, two located in each bay. Flumes were numbered according to spillway bay (4 or 5) and entrance size (A = 0.69 m (2.25')) wide entrance; B = 1.8 m (6') wide entrance; C = 1.2 m (4')wide entrance). Flume number assignments were, from north to south, 4A, 4B, 5C, and 5B (or alternatively, numbers 1 through 4, respectively). Each flume was cantilevered out over the spillway face and led to a tunnel reader that was attached to its end (Figure 2-2). However, this configuration was associated with structural vibration problems in 2000 that led to reduced detection efficiencies. In response, the flumes were "stiffened" at the beginning of the 2001 study by using steel rods attached at one end to the flume and at the other end to the concrete spillway. Tension was applied to the rods by means of turn-buckles, which were adjusted until structural vibrations were minimized. Unfortunately, some residual vibrations remained that could not be corrected, and that were apparently associated with the open channel flow contraction and standing waves occurring in the flumes. This was a greater problem in the two large flumes (4B and 5B). At certain lake levels, standing waves appeared to move slowly through the readers, as manifest by pulses in the outfall water.

The side walls and floor of each flume were constructed of stainless steel screen so that some of the water entering the flume passed through the screens, thereby reducing the amount of water entering the tunnel reader. A larger flow rate was needed at the entrance of the flume than could be passed through the tunnel reader to ensure (i) large attraction flows and (ii) water velocities that significantly exceeded the swimming capacity of the tagged fish as they passed through the flume and reader. Entrance flows to each flume at normal operating capacity were 1.4, 3.7, 2.5, and 3.7 m³/s (50, 130, 90, and 130 cfs) for Flumes 4A, 4B, 5C, and 5B, respectively. Outflows were 0.34, 0.42, 0.40, and 0.42 m³/s (12, 15, 14, and 15 cfs), respectively. The difference between inflow and outflow is the amount that passed through the screen walls of the flumes, and was designed to facilitate visual monitoring or capture of smolts passing through the flumes.

A flow-related operational problem occurred irregularly when the lake level was relatively high, and involved periodic over-topping of the flumes. The amount of water spilling over was relatively small, and occurred in pulses that may have been associated with the transient standing waves. However, a fish stick would occasionally be ejected from the flume in this manner, suggesting the possibility for some fish near the water surface in the flume to suffer a similar fate. Observation of the flumes did not indicate fish were being ejected, suggesting that few if any fish bypassed the tunnel reader when the flume overtopped. Because the number of PIT tagged fish was small relative to the total number of fish passing the Locks, it is likely that if tagged fish were ejected, the number would have been negligible.

The tunnel readers used were Destron-Fearing 134.2 kHz PIT tag monitors. Each tunnel reader contained two independent sets of coil and electronic components that detected and recorded PIT tags separately as they passed through the reader (Figure 2-3). The tag numbers were stored on two computers (one main, one backup) located in the fish ladder maintenance room. The Windows\theta-based MINIMON computer program was used. This program automatically created a new file each day and stored a complete record of detections and self-testing logs for each coil. Relevant data included PIT tag numbers, identification of the coil that detected the tag, and the time and date of detection. The older DOS-based program, MULTIMON, was also used to download data stored in electronic buffers designed into the tunnel reader coil circuitry, to compare with the data stored by MINIMON in cases when computer problems occurred. Data were retrieved from the computers on almost a daily basis. The PIT tag information was extracted using a Fortran program written to filter out other information and pre-process the data prior to QA/QC checking and subsequent data analyses.



Figure 2-2. The smolt flumes, in position and operating at the Locks during spring 2000. Flumes are numbered, from left to right (and north to south), 4A, 4B, 5C, and 5B. View is from walkway next to fish ladder.



Figure 2-3. A PIT tag tunnel reader, prior to its installation at the Locks. Note the two reader coil units. Flow is from left to right through the pipe. The mounting bolts on the left end are for attaching the reader to the flume.

The tunnel reader electronics would go out of phase from time to time, but the exact time when could not be determined. For example, the upstream coils of the tunnel readers in Flumes 4B and 5B appeared to have gone out of phase some time during the week before a calibration test conducted on Friday, May 18, 2001, and were not corrected until the following Monday morning. The electronics were thereafter checked on a regular basis by J. Sadler, who re-tuned them as needed to maximize potential detection efficiency. In addition, Flume 4B was off-line for about two days after the first fish were released in the tributaries and Lake Union (see Appendix B) because an electronic CPU board assembly was not properly installed. This was fixed on May 2, 2001. It is not known the extent to which these problems affected the total number of tag detections evaluated in this study, although it was probably minor given the calibration testing and travel time results presented in Chapter 3, the presence of two independent coils in each unit, and the periodic monitoring by J. Sadler.

2.3 TAGGING, HOLDING, AND RELEASE OF FISH

Juveniles of five salmonid species were tagged: chinook salmon, coho salmon, sockeye salmon, steelhead trout, and one cutthroat trout. PIT tagging was conducted for seven main study groups:

- Calibration groups of hatchery chinook salmon were tagged at the King County/Metro (Metro) Environmental Laboratory and released into the smolt slides. This was done to determine the detection efficiency of the tunnel readers installed at the Locks;
- An experimental group of 5,000 chinook salmon were tagged and released at the Issaquah Hatchery;
- An experimental group of 2,000 University of Washington (UW) Hatchery chinook salmon were tagged and released at the hatchery;
- Naturally-spawned fish were caught by WDFW personnel, tagged, and released at
 different locations in the Lake Washington watershed to evaluate passage characteristics
 of fish using the smolt flumes. Hatchery fish were also caught, tagged, and released at
 some locations. These locations were, specifically:
 - Bear Creek (at the WDFW juvenile outmigrant smolt screwtrap)
 - Cedar River (at the WDFW juvenile outmigrant smolt screwtrap)
 - Lake Washington, west and east of Montlake Cut, including off Webster Point
 - Lake Union, off Gasworks Park

All tagging was conducted using methods described by Prentice et al. (1990c). C.S. McCutcheon, B.A. Turley, and D. Park (Biomark Inc.) tagged hatchery chinook salmon at the Issaquah Creek Hatchery and at the Metro Lab. They were assisted by C. Waldbillig, L. Fleischer, and M. Mizell of WDFW. L. Fleischer tagged fish caught at the Bear Creek and Cedar River screwtraps. Fish caught in Lake Union and east of the Montlake Cut were tagged by S. Achord (NMFS), assisted by C. Waldbillig, L. Fleischer, and M. Mizell (WDFW) and D. Frost (NMFS).

Tagging operations involved insertion into the abdominal cavity using a large bore syringe, and measuring the length of the fish on a custom digitizing pad. Data for individual fish were collected using one or two data collection stations (Biomark brand) equipped with Pacific States Marine Fisheries Commission (PSMFC) software (PITTAG2.EXE). The PIT tag number and fish length data were scanned into a PIT Tag Information System (PTAGIS) format file for submission to the PSMFC database maintained in Portland, Oregon (the files were edited for mortalities and tag loss before submission). After tagging, the needles on the syringes were disinfected in an ethyl alcohol bath for a minimum of 10 minutes before being reloaded and reused.

Twenty-four-hour post-tagging mortalities were noted for the fish held at the UW hatchery, metro, and selected groups of the fish captured at other sites.

Letter reports from S. Achord and L. Fleischer detailing 2001 tagging activities and mortalities are presented in Appendix A. Their reports are summarized in the following subsections.

Releases of PIT tagged fish were designed to address questions regarding (i) differential survival rates along portions of the migration route, and (ii) the nature and variation of outmigration characteristics in the Lake Washington watershed. Release locations are depicted in Figure 1-1.

2.3.1 Issaquah Hatchery Chinook

A total of 5,014 age 0+ chinook salmon originating from the Issaquah Creek hatchery were tagged on location on April 9-10, 2001, held, and 4,676 were ultimately released as part of a group of 528,000 chinook smolts on May 15, 2001 into Issaquah Creek (another 1,558,000 smolts were released on May 22; C. Waldbillig, WDFW, personal communication). The fish were held in the outdoor raceways with other non-tagged fish. Tagging was done at the same time that the fish were being fin-clipped by hatchery personnel. The fish were anaesthetized and

clipped, and transported in water by gravity flow through a pipe to one of the raceways. Fish for PIT tagging were intercepted at the pipe outfall using a large net and were selected randomly. It was noticed during tagging that many fish had received incomplete or ineffective adipose finclips that might confound later identification of fish origin. The fish were transported in buckets to two tagging stations, anaesthetized again, tagged, and released back into the raceway to mix with the other fish once they had recovered from the anaesthetic.

C. McCutcheon (Biomark) taught WDFW personnel how to tag fish. Tagging was performed by an individual for a few hours at a time, at which point another person would take over. The fish were relatively small (length generally between 55-75 mm) and thus difficult to tag. Water temperatures were relatively cold (on the order of 5°C), and only a few fish died during tagging. The overall tag shedding rate during the holding period was relatively high at 6.7% (338 tags), with the majority associated with shedding based on recoveries from the raceway bottom using a powerful magnet and a later check after draining. A review of the sequence of data in the original tagging file for each station indicated that the majority of shed tags occurred in clusters, suggesting that there was variability in tagging ability between individuals.

2.3.2 Metro Laboratory Chinook

There were two groups of fish held at the Metro Laboratory. The second group was transported, tagged and held once the first group had been used up in calibration testing.

For the first group, approximately 1,000 chinook from the Issaquah Creek Hatchery were transported to the Metro Laboratory in early April 2001, of which 973 were tagged on April 11, 2001. The fish were anaesthetized by WDFW personnel prior to tagging using MS-222, to reduce stress and injury during tagging. Fish were removed using standard dip nets and groups of approximately 60 fish were placed in 19 liter (5 gallon) buckets and carried to the tagging tables by WDFW personnel. Small groups of approximately 20 fish were then dipped and anaesthetized prior to tagging. Fish smaller than 55 mm were not tagged. The total mortality and shed tag rate over the holding period was 2.8% (27 tags).

For the second group, roughly another 1000 chinook were transported from the Issaquah Creek Hatchery to the Metro Laboratory on April 24, 2001, of which 1013 were tagged on May 2, 2001. These fish were held longer after tagging than the first group and the tagging wounds took a long time to heal. Consequently, the total mortality and shed tag rate over the holding period was much higher than for the first group, at about 19% (191 tags). Residual fish remaining from the second group were released on the morning of July 3, 2001.

The fish from each group were divided among eight 0.9 m (3') diameter tanks set up inside in the bioassay lab of the building. Water used to hold all fish at the Metro Laboratory consisted of UV-treated lake water that was chilled when necessary to reach a target holding temperature of 10°C (50°F). The fish were designated for release as calibration test fish for evaluating the detection efficiency of the tunnel readers. The fish were provided and managed by K. Fresh of WDFW, who also oversaw design, construction, and maintenance of all fish holding facilities, care of the fish, and transportation and release of the fish at the respective release locations. King County personnel provided assistance and fish care at the Metro Laboratory.

2.3.3 University of Washington Hatchery Chinook

2,015 chinook salmon juveniles rearing at the UW hatchery were PIT tagged on April 12, 2001. These fish were released into the LWSC as part of the regularly scheduled UW hatchery release on May 21, 2001 around 18:00. However, a rain event that occurred on May 15, 2001 resulted in holding pond overflow and the premature release of an unknown number of tagged fish into the LWSC.

2.3.4 Tributary Fish

Juvenile chinook, coho, and sockeye salmon, and steelhead trout were caught and tagged at WDFW downstream migrant screw traps (see, e.g., Thedinga et al. 1996 for a description of a screw trap) in two streams in the Lake Washington system. The sites were located in (i) lower Bear Creek, below the railroad trestle, downstream of Redmond Way, and (ii) in the lower Cedar River just upstream from the Logan Street Bridge (Figure 1-1). Tagging was initiated at both sites on May 2, 2001. Tagging continued until July 9 in Bear Creek, and July 20, 2001 in the Cedar River. Tagging dates encompassed the peak of the outmigration period for naturally-produced smolts. A total of 2,882 fish were tagged and released in the Cedar River, and 3,158 fish in Bear Creek. Most of the fish were chinook and coho salmon, although a few steelhead trout and sockeye salmon were also tagged. A primary goal of this portion of the study was to determine survival and migration characteristics of the main fraction of the run for each species in each stream.

Fish were collected overnight in the screw traps. On each day of tagging, fish trapped the night before were transferred using sanctuary dip nets to 5 gallon buckets and then to a small tub containing MS-222. A PIT tag was inserted into the anaesthetized fish, which were then

returned into a recovery bucket. Fish were allowed to recover fully from the anaesthetic before they were released back directly into the river below the screw trap, usually within an hour after tagging. In general, all or nearly all chinook, coho, steelhead, and sockeye present in the trap that day were tagged, except for a few fish that were smaller than about 60 mm in length, which were too difficult to handle and for which the tag was large relative to the abdominal cavity size. Fish tagged in Bear Creek and the Cedar River were almost exclusively naturally reared fish. The tagged chinook were likely all sub-yearlings, whereas it is likely that most of the coho and steelhead were yearlings (see report in Appendix A).

2.3.5 Lake Union and Montlake Cut Fish

Juvenile chinook, sockeye, and coho salmon were collected at two locations to determine migration characteristics in the LWSC: (1) in Lake Union, offshore of Gasworks Park, and (2) in the vicinity of the Montlake Cut, in Union Bay near Webster Point, and in Portage Bay near the west end of the Cut. In Lake Union, fish were captured by D. Seiler and WDFW personnel using a purse seine. The Montlake Cut fish were captured by K. Fresh and WDFW personnel using a beach seine, with the majority caught at Webster Point (> 95%; C. Waldbillig, WDFW, personal communication). The captured fish from both sites were transported in 114 liter (30 gallon) or 150 liter (40 gallon) transfer containers to a NMFS marking barge for PIT tagging that same day. The barge was moored at the Seattle Police dock located on the north shore of Lake Union. Lake water was pumped through the containers during transport using battery operated bilge pumps. On arrival to the marking barge, fish were transferred to one of two large, oxygenated holding tanks that were continuously supplied with fresh lake water.

Tagging was performed by NMFS personnel (see S. Achord's report in Appendix A). Capture and tagging at both sites began May 1, 2001 and continued until June 26, 2001 when water temperatures approached levels that tagging operations began to be associated with substantially higher mortality rates. Fish were transferred from the fish holding tank to another using sanctuary dip nets and anaesthetized using MS-222. Fish were scanned with a hand-held PIT tag reader to check for recaptured individuals that had already been tagged. Previously tagged fish were measured for length and their general body condition was noted. Fish were PIT tagged one by one and scanned into the PIT tag file. Some PIT tags left over from mortalities the previous year were reused in 2001, and were sterilized in alcohol for more than a month prior to use. Fish length was digitized and comments recorded when appropriate regarding condition of fish or tagging operation details. The origin of each fish (hatchery or natural) was recorded by noting the absence or presence of the adipose fin. The tagged fish were then put in the other large fish

holding tank on the barge to recover. After tagging was completed, fish were allowed to recover in the fresh water tank for a minimum of a half hour.

The marking barge was moved to the release site after tagging. Mortalities were removed, and the remaining fish were subsequently released mid-channel through a 10 cm (4") flexible hose. The Lake Union fish were released approximately 100 meters east of the Fremont Bridge to increase their probability of survival from predation (there appear to be relatively few predators in the Fremont Cut; K. Fresh WDFW, and R. Tabor USFWS, pers. comm.). The Montlake fish were released in the Montlake Cut. Because the release locations for the Lake Union and Montlake fish were consistently and generally closer, respectively, to the Locks than their capture location, these fish may have incurred a lower overall mortality rate than fish that were not captured and tagged. Of the two groups, the potential for bias may be greater for the Montlake fish, which were effectively transported past potential predator habitat in Union Bay.

Study objectives were to tag between 5,000 and 6,500 fish at each site. Tagging was discontinued after June 26, 2001, because water temperatures had increased sufficiently (to 17-18°C) to result in significantly increased tagging mortality of chinook smolts (see Appendix A). A total of 4,800 fish were tagged and released at the Lake Union site according to the tagging files, and 908 fish at the Montlake site. Overall collection mortality was 0.3% and post-tagging mortality (less than 24 hours) was 4.1%. Most mortalities were of chinook salmon (8.1%; see Appendix A for more details).

2.4 CALIBRATION TESTING OF THE TUNNEL READERS

The chinook salmon held at the Metro Laboratory were designated primarily as calibration test fish. Calibration test fish were released in small groups on five separate occasions between April 23 and July 3, 2001 to evaluate the detection efficiency of the tunnel readers. Groups of between 20 and 70 fish were released directly into the mouth of each flume through an angled PVC pipe. Visual observation during the 2000 study by D. Houck, King County using an underwater camera during one of the tests indicated that less than 1% of the fish on average may have escaped from the mouth of a flume during testing. There were no escapees detected in the tunnel readers subsequent to the tests in 2001, suggesting that all calibration test fish passed through the flumes during the tests.

"Fish sticks" were constructed to supplement the live fish, so that they could be used more frequently and reduce the study's dependence on fish being held at the Metro Laboratory. The sticks were constructed out of 30 cm lengths of 1.9 cm (sold as ³/₄") x 1.9 cm hemlock stock

wood. A small hole was drilled and a PIT tag was inserted and sealed in. Two types of sticks were constructed: (1) where the tag was oriented parallel (0°) to the long axis of the stick, and (2) where the tag was oriented 45^B to the long axis. Ten sticks of each type were dropped sequentially into each flume, in such a manner that they entered the tunnel reader approximately parallel to the flow streamlines thereby mimicking the passage of PIT tagged fish. The sticks were painted with bright fluorescent colors to facilitate retrieval using a boat below the flumes.

The number of test fish and fish sticks that were detected was determined from the file created by MINIMON. Detection efficiency was calculated as the ratio of number detected to number released in each flume, expressed as a percentage. Electronic marker notes were placed in the computer file immediately before each live fish group was released and the time noted in field books so that the detected tag codes and discrete flume tests could be distinguished accordingly. A FORTRAN program was written to extract the fish stick data and summarize those results.

2.5 DETECTION STRATEGY

The study was designed to detect fish at and below the Locks from primarily a feasibility perspective. Hence, not all of the passage routes through the Locks were monitored, and an unknown proportion of tagged fish passed downstream without being detected. This feature of the study influenced the accuracy and precision of survival estimates, but did not substantially influence evaluations of migration characteristics.

The tunnel readers were the primary means for detecting PIT tagged fish released above the Locks, and were operating 24 hours a day, regardless of whether the smolt flumes were open or closed. Hand-held readers were also used to scan for tagged fish in the Montlake and Lake Union catches prior to tagging, in purse seine samples collected in the large lock, and in beach seine samples collected below the Locks. All fish caught in the purse seine were released below the chamber, with the center gate kept closed to prevent their re-entrance during subsequent sampling. However, sampling effort was inconsistent over the study period because goals of the purse seining were associated primarily with evaluating entrainment into the filling culverts, and the size of the catches was frequently large. As a consequence, sampling for PIT tagged fish was a secondary objective and scanning was intermittent.

There were no detection facilities or sampling conducted in the small lock, the other spillway gates, the saltwater drain, or the fish ladder.

PIT tags were scanned for in beach seine samples collected beginning on 5/30/01, and continuing through the summer. Sampling was conducted at 11 sites (J. Toft, pers. comm.), 7 of which were located within the vicinity of the inner bay and 4 in Puget Sound proper (Figure 2-4). A 30 m long beach seine was used. Sampling in a given site was conducted consistently around the specific tide level at which it was judged that seining could be performed most effectively. All captured salmonids were held temporarily in large tubs and buckets, and checked for pit-tags by passing each fish through the antenna of the hand-held detector. The sampling was conducted collaboratively by USACE, WDFW and UW study participants. Sampling effort was most intensive during the week of June 18, 2001, during which time both day and night sampling was done in an effort to collect as many PIT tags as possible during the peak chinook outmigration period. Sampling occurred weekly throughout the rest of the outmigration period until mid-September, after which sampling was performed biweekly until mid October.

An effort was made on July 12, 2001 to evaluate the feasibility of collecting fish using a purse seine below the Locks. Two sets were made, one in the channel below the Locks and the other near Golden Gardens. The net got snagged on the first set, and only two smolts were captured. The other set captured a large number of mostly non-salmonid fish. None of the fish caught were tagged.

Sampling was also conducted periodically for PIT tags in the Sammamish River during the spring and early summer of 2001 (Jeanes and Hilgert 2002). Two fish from the Issaquah Hatchery release were detected on different dates, but the hand-held detector malfunctioned and did not store the tag number of the first fish. Those two detections were evaluated in this report.

2.6 DATA ANALYSES

2.6.1 Physical Characteristics of the Fish

Other than general body condition at time of tagging, the only physical characteristic of the tagged fish that was measured was total length at time of tagging, and whether the fish could be discerned to have been of hatchery origin. Almost all of the tagged fish were measured, with the exception of a small number whose lengths were inadvertently not recorded by the digitizing system. Fish recaptured in the Montlake Cut and Lake Union tagging operation were remeasured for length, providing some information on growth rates. Not all fish with PIT tags detected in beach seine samples below the Locks were measured for length, in order to reduce the time of handling and potential for shock. For similar reasons, only a subset of fish detected in the purse seine sampling in the large lock were measured. Hence, information was generally

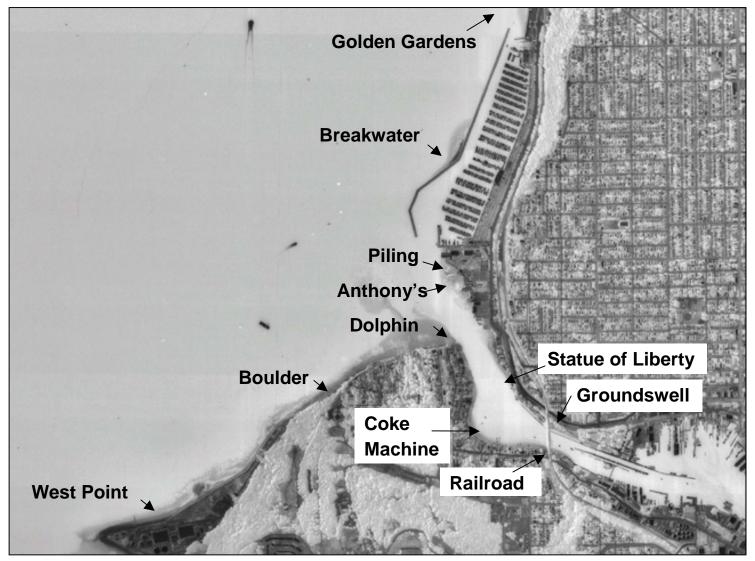


Figure 2-4. Location of beach seining sites sampled in the inner and outer bay areas below the Locks, 2001 Lake Washington GI Study. (Photo from J. Toft, University of Washington)

unavailable regarding growth and length at time of passage at the Locks. Instead, fish lengths at time of tagging were used primarily to compare potential size differences between the detected and undetected fish by means of frequency analysis using a Chi Square test of observed (=detected fish) and expected (=released fish) frequencies (Zar 1984). This was done for each group as a whole, irrespective of release date to see if there were any population-level differences in fish length arriving at the Locks compared with lengths at other points along the migration route.

The length data from the Lake Union, Montlake Cut, Cedar River, and Bear Creek tagging operations were also used to compute average lengths of tagged fish at different times at each location. The results were plotted against date to identify temporal trends, if any, that might potentially influence size-dependent survival to the Locks, or suggest partitioning of the length frequency data by tagging date.

2.6.2 Migration Behavior

The dates of PIT tag detections at the Locks were used to identify patterns and differences in migration timing, total travel time until passage through the flumes, and average migration rate among the different test groups. Average migration rate was computed by dividing travel distance by the number of days between release and detection at the Locks. Travel distances were determined using the "Topo" software package (\(\theta\)Wildflower productions) by tracing assumed migration routes five times on electronic topographic quad sheets and averaging the numbers calculated by the program. Routes in the LWSC were assumed to follow the midchannel line on average. Routes through Lake Washington were assumed to follow the west shoreline from either the mouth of the Cedar River, or the mouth of the Sammamish River, where the path as traced ran within approximately 400 m (½ mile) offshore (note, however, that some fish exiting the Sammamish River were determined during this study to have likely migrated along the eastern shore of Lake Washington; see Section 4.0). Traced routes through Lake Sammamish followed both west and east shorelines and an average was taken of the two.

2.6.3 Passage Behavior at the Locks

The dates and times of PIT tag detections at the Locks were used to identify patterns and differences in seasonal and daily passage timing among the different test groups at the Locks. Tag codes were also evaluated for recycling times through the Locks, based on repeated detections at the tunnel readers and/or in purse seine samples in the large lock.

To evaluate the influence of filling of the large and small locks on smolt passage through the flumes, detection times were compared with times at which various components of the Locks were operating. Fortran programs were written that counted the number of detections that occurred while (i) the small and large locks were filling and for five minutes thereafter ("fill" period), and (ii) until the time of the next fill sequence ("between-fill" period). Time of lock openings were determined from records maintained by the Lockmaster, and the time for each lock to fill was determined as a function of tide elevation and observations of fill times at different tide levels. In the case of the large lock, the fill time was also a function of whether one or both chambers were being filled and how fast the water was allowed to flow through the culverts (i.e., continuous, gradual, or intermediate fill patterns). A post-fill period of five minutes was selected arbitrarily (absent specific data), assuming that fish continued to swim about actively for a short period after the velocity field in the spillway dam forebay returned to approximately steady-state, non-fill conditions. The exact time for velocities to return to steady state has not been determined in recent measurements of velocity fields above the Locks, but appears to be less than 5 minutes based on available measurements (Johnson et al. 2001). Velocity transients associated with density currents when the upper gates are opened (Lingel 1997) were not considered.

The two sets of numbers generated by the programs were compared using t-tests to evaluate the hypothesis that transient changes in water currents in the vicinity of the Locks caused by lock filling operations were associated with increased passage through the flumes. The null hypothesis was that passage was not significantly different in pairwise comparisons of sequential observations of numbers of fish passing through the flumes during and between fills.

2.6.4 Estuarine Behavior

The dates and times that PIT tagged fish were detected in beach seine samples were compared with detection time and date at the Locks, or with release dates if not detected at the Locks. The intervening times were computed and evaluated with respect to location of release above and capture below the Locks, and salinity characteristics below the Locks. The time between detection in the flumes and recapture represented the maximum possible for transition to saltwater (salinity > 20 ppt).

2.6.5 Survival Estimation

Survival could not be estimated to high accuracy or precision because (i) of low numbers of recaptures below the Locks (see Section 3.1), (ii) a control group of PIT tagged fish was not

released below the Locks to estimate beach seine capture efficiency, (iii) the proportion of tagged fish using the smolt flumes compared with other routes through the Locks had to be estimated as well, (iv) of variable tunnel reader detection efficiencies (see Section 3.2), and (v) seasonal variation in detection rates, possibly related to increasing water temperature in the LWSC, was likely reflected in a change in the proportion using the flumes (see Section 3.7). Nevertheless, it was possible to use the detection numbers to evaluate relative differences in survival along segments of the migration route above the Fremont Cut, for distinct periods during the outmigration season, because the proportion using the flumes cancels out in the corresponding survival calculations (see below).

Survivals were estimated for each chinook release group by comparing the number of fish released ($N_{group\ REL}$) with the number of fish detected at the smolt flumes ($N_{group\ SF}$), subject to the proportion using the flumes and the detection efficiency of the tunnel readers. Survivals were not estimated for coho or sockeye release groups. In general, the following steps and assumptions were made to estimate survival over the different portions of the migration route depicted in Figure 2-5.

The total number of PIT tagged fish from each release group passing through the four smolt flumes was estimated using an average detection efficiency for each flume i (E_{SFi} ; determined during the calibration testing):

$$\hat{N}_{group_{SF}} = \sum_{i=1}^{4} \hat{N}_{group_{SF}i} = \sum_{i=1}^{4} \frac{N_{group_{SF}i}}{\overline{E}_{SF}i}$$

Let the fraction of tagged fish arriving at the Locks that pass downstream through the flumes equal P_{SF} . Assuming that this value influences all survival estimates the same, the relative differences in survival estimated for different portions of the outmigration routes should be approximately preserved. The survival of each group (S_{group}) was thus estimated as:

$$\hat{S}_{group} = rac{\hat{N}_{group_{SF}}}{\hat{P}_{SF} N_{group_{PFI}}}$$

This is equivalent to the maximum likelihood estimator of Burnham et al. (1987; p.114).

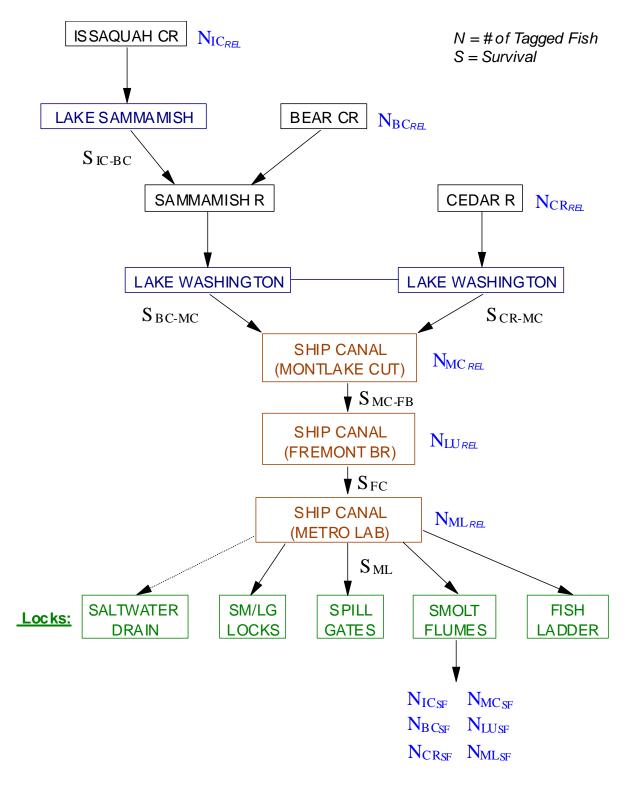


Figure 2-5. Schematic of migration routes in the Lake Washington and LWSC system, and associated survivals along segments of the route. Notation is described in the text.

The proportion passing through the flumes (after correcting for tunnel reader efficiency), which is analogous to the probability of detection at the Locks, can be estimated using the following equation (Burnham et al. 1987; p.114; the corresponding computer program "Release" was used here):

$$\hat{P}_{SF} = \frac{m_{t23}}{m_{t13} + m_{t23}}$$

where:

 m_{t13} = Number of PIT tagged fish caught in beach seine samples below the Locks, but not detected in flumes

 m_{t23} = Number of PIT tagged fish in beach seine samples, and detected in flumes

However, the proportion using the flumes could not be estimated with high precision because of small numbers of recaptures below the Locks. As a consequence, survival could not be estimated with high precision for the segments between the Fremont Bridge (FB) and the Locks because the proportion using the flumes is not known with great certainty. Survival could be estimated for the following route segments:

• From the Montlake Cut (MC) to the Fremont Bridge:

$$\hat{S}_{MC-FB} = \frac{\hat{S}_{group=MC}}{\hat{S}_{group=LU}}$$

• From the Cedar River (CR) trap to the Montlake Cut:

$$\hat{S}_{CR-MC} = \frac{\hat{S}_{group=CR}}{\hat{S}_{group=MC}}$$

• From the Bear Creek (BC) trap to the Montlake Cut:

$$\hat{S}_{BC-MC} = \frac{\hat{S}_{group=BC}}{\hat{S}_{group=MC}}$$

• From the Issaquah Creek (IC) Hatchery to mouth of Bear Creek (assuming negligible mortality between the Bear Creek trap and mouth):

$$\hat{S}_{IC-BC} = \frac{\hat{S}_{group=IC}}{\hat{S}_{group=BC}}$$

Because of apparent seasonal variation in the proportion using the flumes, the calculations need to reflect similar passage timing at the Locks by the different groups used, so that P_{SF} can be cancelled out in the above equations. The travel time results were used to determine which chinook release groups to evaluate together. To increase sample size, a weekly time step was used to determine release groups and their respective detection rates at the Locks. In the case of the groups that were tagged and released over the course of the passage season (tributary and LWSC groups), the average travel time for each release group was approximated by taking the difference of the 50th percentile values of the cumulative distributions for number of fish tagged and detected by date (see Section 3.4). The 50th percentile detection date was used to approximate the representative travel time for the Issaquah hatchery chinook release group. The UW hatchery fish were not evaluated because the results indicated their behavior was markedly different from the others'.

Based on the travel time information, the following weekly groups of chinook releases were assumed to have experienced similar survivals over shared segments of the migration route:

Comparison 1:

- Bear Creek (~4 week travel time) groups released week of 5/14/01
- Cedar River (~3 week travel time) groups released week of 5/21/01
- Montlake Cut (~2 week travel time) groups released week of 5/28/01
- Lake Union (~2 day travel time) groups released week of 6/4/01

Comparison 2:

- Issaquah Hatchery (50th percentile detected week of 6/12/01; ~5 week travel time) released week of 5/14/01 (on 5/15/01)
- Bear Creek groups released week of 5/21/01
- Cedar River groups released week of 5/28/01
- Montlake Cut groups released week of 6/4/01
- Lake Union groups released week of 6/11/01

Comparison 3:

- Bear Creek groups released week of 5/28/01
- Cedar River groups released week of 6/4/01
- Montlake Cut groups released week of 6/11/01
- Lake Union groups released week of 6/18/01

Comparison 4:

- Bear Creek groups released week of 6/4/01
- Cedar River groups released week of 6/11/01
- Montlake Cut groups released week of 6/18/01
- Lake Union groups released week of 6/25/01

These groups were selected because they represent a substantial fraction of the fish passing through the smolt flumes during the main chinook outmigration period, and thus are represented by the highest detection rates. There were few, if any, detections of fish from selected groups in other weeks not represented here.

Variance of Survival Estimates:

The variance estimate for the survival estimate is (Burnham et al. 1987; p 115):

$$\hat{V}ar(\hat{S}_{group}) = (\hat{S}_{group})^2 \left[\frac{1}{m_{t12} + m_{t13}} - \frac{1}{N_{group_{REL}}} + (1 - \hat{P}_{SF})^2 \xi \right]$$

$$\xi = \frac{1}{m_{t23}} - \frac{1}{m_{t12}} + \left[\left(1 - \frac{m_{t23}}{m_{t12}} \right)^2 \left(\frac{m_{t12}}{m_{t13} (m_{t12} + m_{t13})} \right) \right]$$

where:

 m_{t12} = Number of PIT tagged fish passing through flumes (assumed unharmed).

The variance estimate for the proportion using the flumes is (Burnham et al. 1987; p 115):

$$\hat{V}ar(\hat{P}_{SF}) = (\hat{P}_{SF}(1 - \hat{P}_{SF}))^2 \left[\frac{1}{m_{t23}} + \frac{1}{m_{t13}} \right]$$

These estimates do not include other sources of uncertainty. One source is error in the detection efficiency estimate. However, the effect of this source of uncertainty is small relative to sampling variation because the detection efficiencies generally were within +/- 5% of the mean for each flume (see calibration testing results).

The variance of route-increment-survival estimates can be estimated using the first order approximation:

$$\hat{V}ar\left(\hat{S} = \frac{S_1}{S_2}\right) \approx \frac{\hat{V}ar(\hat{S}_1)}{\left(\hat{S}_2\right)^2} + \frac{\left(\hat{S}_1\right)^2 \hat{V}ar(\hat{S}_2)}{\left(\hat{S}_2\right)^4}$$

3. RESULTS

The results of this study were less influenced by water conservation needs in 2001 than in 2000. Nevertheless, by mid-June, the volume of water available in the lake for operating the flumes, locks, fish ladder, and saltwater drain was insufficient to run all the flumes continuously through the remainder of the passage season. The decision was therefore made by the USACE to shut down Flume 4A, and run Flume 4B intermittently as long as possible. Flumes 5B and 5C were then kept running as long as possible until water was no longer available to operate them. After the first week in July, the flumes were operated only during the day, because the results from 2000 indicated that the majority of fish passed during daylight hours. Flume 5B was selected as the final flume to keep open because previous year's results indicated that the larger flume passed more fish. Figure 3-1 shows the times that the flumes were open during the study, according to logs kept in the lock control tower and PIT tag detection times. There were also short periods when the flumes were closed for maintenance. Consequently, the coverage for PIT tags was neither continuous nor consistent.

There was a computer problem that occurred in late May (Figure 3-1). The Minimon program stopped recording tags on May 26, 2001. This continued over the weekend until the problem was noticed on Monday, May 28, 2001 during regular data downloading by K. Bouchard. The computers were reset, but the problem occurred again the next day. It was deduced from investigation that the number of files (>600) in the data directory on the computer was excessive, and was likely causing the program to crash. The directory was cleaned up, and the problem did not reoccur. Tags that were detected as they passed through the flumes during those two periods were downloaded from the tunnel reader buffers. Unfortunately, the day and time that the tag passed could not be ascertained exactly because the buffer did not record that information. Data from the two periods are identified accordingly in this report.

The flumes operated long enough that the numbers of tagged chinook passing through the flumes had decreased substantially to near zero, consistent with visual flume count data (P. Johnson and K. Bouchard, personal communication). Behavioral patterns evident in the data were therefore unlikely to have been influenced significantly by systematic error. These patterns relate to migration, passage, and the transition to saltwater, and provide significant insight into the basic biology of juvenile outmigrant salmonids in the Lake Washington system. A substantial portion of this section reports on these behavioral features. Rough estimates of survival are also presented, although it must be re-emphasized that they are likely to be highly imprecise for reasons explained later.

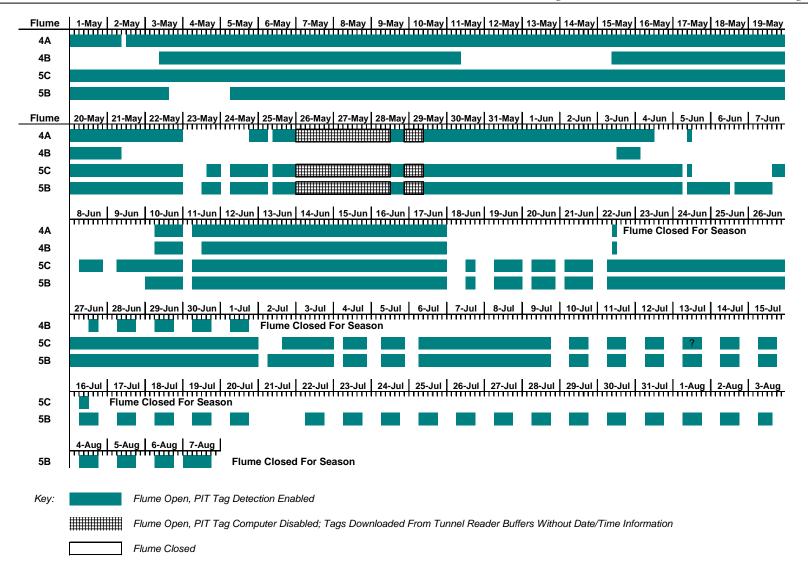


Figure 3-1. Times that the smolt flumes were open at the Locks during the 2001 PIT tag study after the first test fish were released.

3.1 PIT TAG DATA SUMMARIES

Table 3-1 summarizes numbers of fish and the locations at which they were tagged and released. The estimated numbers passing through the flumes reflect corrections based on average detection efficiencies determined for each flume in the calibration tests. Figures 3-2, 3-3, and 3-4 depict the numbers and dates of tagging for each group and release location. The numbers and dates of release of each species at each location, and the corresponding numbers detected in each flume are also presented in tabular form in Appendix B.

Immediate tagging mortalities and losses were negligible in the tributary and LWSC sampling, and was on the order of 1% or less for most groups except in special cases (e.g., overcrowding-related stress during handling, and when water temperatures in the LWSC exceeded about 17°C). Overnight mortality rates were determined for a subset of the LWSC groups. Although the majority of rates were close to zero, there were several instances of greater mortality, where the values ranged from 0% to 1.7%, 0% to 15%, and 0% to 24% for coho, sockeye, and chinook, respectively (see Appendix A). Overnight mortality rates determined for a subset of the tributary fish were 1.7% and 2.9% for chinook and coho respectively in Bear Creek and the Cedar River combined (Appendix A). Overnight tag retention rates in the LWSC were close to 100%.

Tagging mortality was not determined for the Issaquah Hatchery chinook but was probably negligible as few dead fish were seen afterward. However, subsequent recovery of tags from the bottom of the raceway where the fish were held indicated an overall tag loss rate of 6.8% for those fish over the 5-week holding period. The loss rate in these fish was likely high because of their small size at the time of tagging, and the difficulty in working outdoors with such small fish under what were a combination of cold weather and water conditions. There were also distinct blocks in the tagging files where mortalities occurred more frequently, suggesting differential tagging effectiveness among the taggers.

There were 34 tags detected in the tunnel readers that were not identified in the original tagging files, probably because they were not detected by the tagging station equipment, so the origin of those fish could not be determined. They did not include any fish tagged in 2000.

Table 3-1. Summary of 2001 PIT tag release and tunnel reader re-detection numbers, Lake Washington GI Study

Species	Origin	Issaquah Creek Hatchery	Bear Creek	Cedar River	Montlake	UW Hatchery	Lake Union	Metro Laboratory		
	Total Numbers Tagged and Released:									
Chinook	Natural		2132	1550	67		114			
	Hatchery	4676		67	635	2015	1892	204		
Coho	Natural		1011	1235	37		239			
	Hatchery		12		5	5				
Sockeye	Natural			8	164		2219			
Steelhead	Natural		3	22			3			
	Total Numbers Detected in Smolt Flumes:									
Chinook	Natural		249	413	19		41			
	Hatchery	1630		4	235	996	593	21		
Coho	Natural		439	556	10		115			
	Hatchery				3		114			
Sockeye	Natural			1	42		1258			
Steelhead	Natural		0	5			1			
	Estimated Total Numbers Passing Through Smolt Flumes:									
Chinook	Natural		270	446	20		45			
	Hatchery	1762		4	252	1073	643	22		
Coho	Natural		471	599	10		125			
	Hatchery				3		123			
Sockeye	Natural			1	44		1361			
Steelhead	Natural		0	5			1			

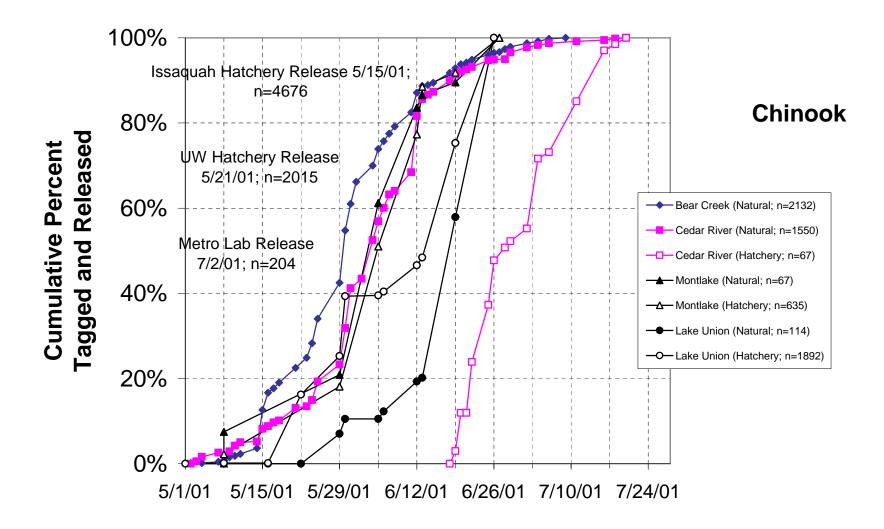


Figure 3-2. Cumulative frequency distributions of juvenile chinook salmon PIT tagging numbers by date and location, 2001 Lake Washington GI study.

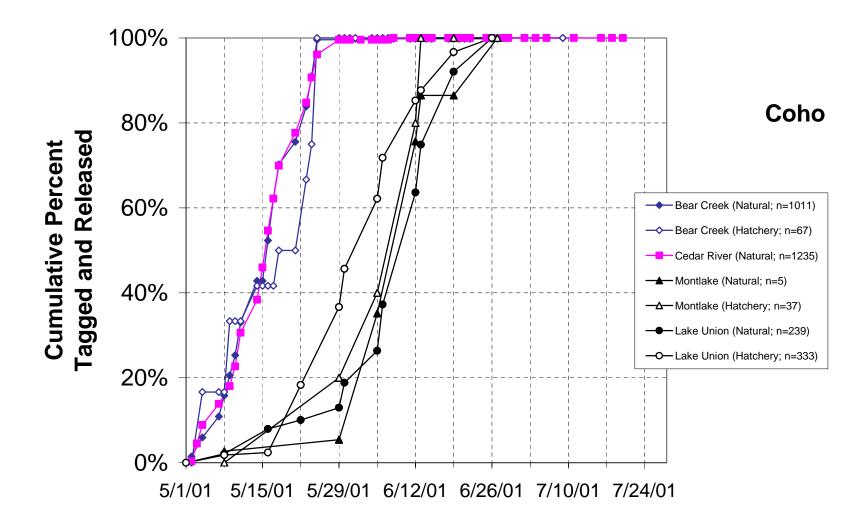


Figure 3-3. Cumulative frequency distributions of juvenile coho salmon PIT tagging numbers by date and location, 2001 Lake Washington GI study.

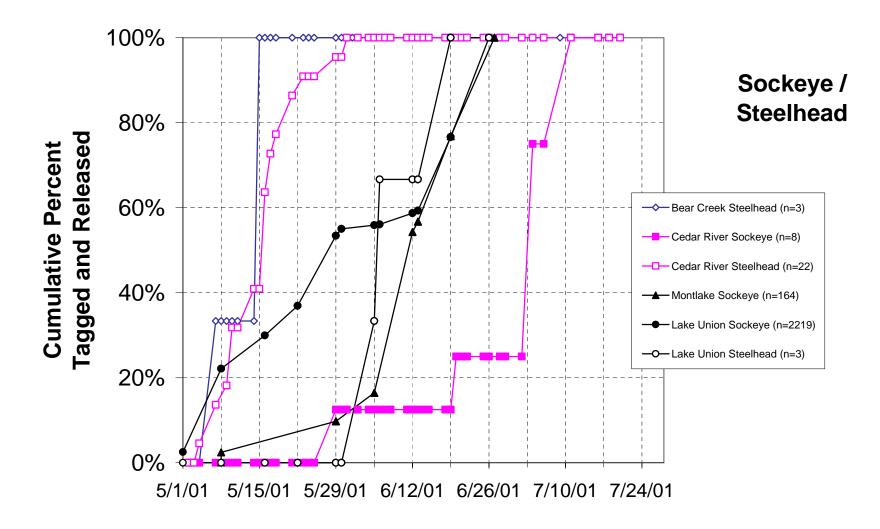


Figure 3-4. Cumulative frequency distributions of juvenile sockeye salmon and steelhead trout PIT tagging numbers by date and location, 2001 Lake Washington GI study.

3.2 CALIBRATION TESTING AND FLUME/TUNNEL READER OPERATION PROBLEMS

Detection efficiency was improved in 2001 compared with 2000. This was a result of structural modifications that were developed to reduce vibration of the cantilevered flume assembly. This is the only installation of PIT tag readers where they are not rigidly supported (D. Park, Biomark, personal communication). The vibration was occurring at a frequency that interfered with tag detection (see DeVries [2001] for more detail). Modifications included installation of crossbraces and experimenting with the amount of de-watering through the flume side panels. These modifications were sufficient to improve the detection efficiency to recommended levels in the small and mid-sized flumes (4A, 5C), but not in the two large flumes (4B, 5B). In addition to decreased effectiveness, variation in detection efficiency increased with flume size (Figure 3-5). Guidelines for the Columbia River require a minimum detection efficiency of 95% with four coils operating, and most systems there operate in the 98-100 percent efficiency range (D. Park, Biomark, personal communication). Beginning in May after study fish were released, detection efficiencies based on calibration test fish averaged 99% and 98% in Flumes 4A and 5C, and 89% and 90% in Flumes 4B and 5B, respectively. These values were used to estimate the expected total numbers of PIT-tagged fish passing through the flumes, as described in Section 2.6.5. The resulting estimates are summarized in Table 3-1 for each release group.

The calibration tests also indicated that the fish sticks with tags oriented parallel to the flow in the flumes were detected with greater efficiency on average than were live tagged fish (Figure 3-6). In contrast, the fish sticks with tags oriented at 45° were detected at a similar rate as the tagged fish. Visual observation of fish passing through the flumes indicated that they swim vigorously facing upstream, and thus their bodies are not always oriented optimally for detection.

3.3 FISH LENGTH CHARACTERISTICS

Fish lengths were determined primarily at the time of tagging, and with the possible exception of fish caught in Lake Union, the large lock, and in the beach seining below the Locks, should not be used to infer size at time of passage at the Locks. Figures 3-7 through 3-19 depict the range and frequency distributions of lengths of the fish that were tagged in each group, and compares the distributions with those of the fish that were detected at the Locks. The figures also depict the change in mean length of fish at the LWSC and tributary locations where tagging continued over the course of the passage season. In general, there was limited evidence of a consistent effect of fish size on detection rate at the Locks, indicating that tagged fish generally had an equal probability of passing through the flumes. In most cases, the two distributions were not significantly different and overlapped at the 5% significance level (Chi-Square test of expected frequencies; Locks = observed, tagging = expected).

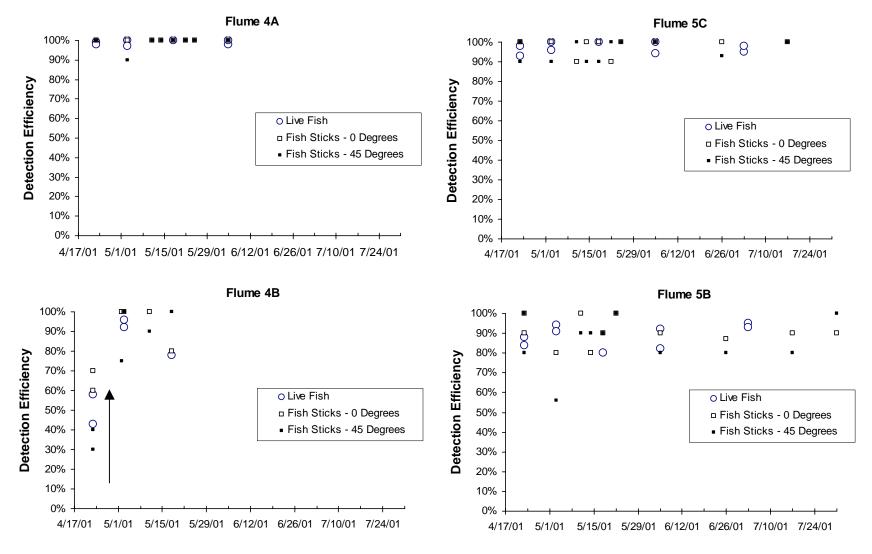


Figure 3-5. Results of calibration tests of tunnel detector efficiency at the Locks using PIT tagged fish and fish sticks released directly into each flume. Tags were inserted in fish sticks at the angles indicated, from the line parallel to the flume long axis, 2001 Lake Washington GI study.

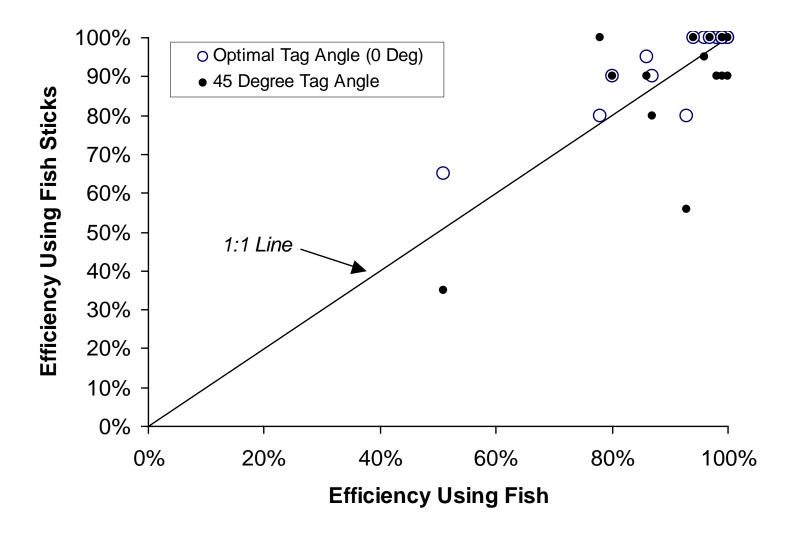
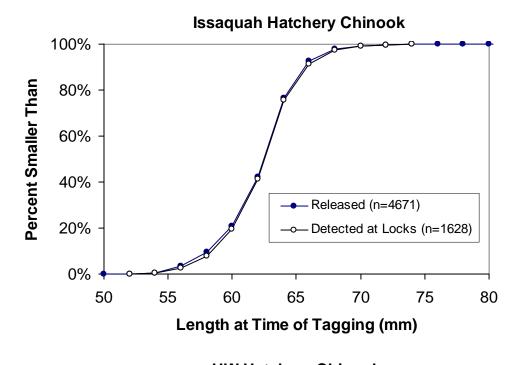


Figure 3-6. Comparisons of tunnel detector efficiencies at the Locks determined using live fish and fish sticks, 2001 Lake Washington GI study.



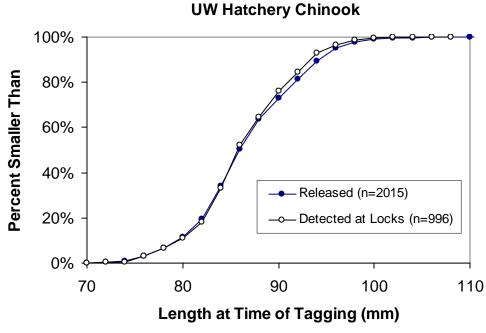
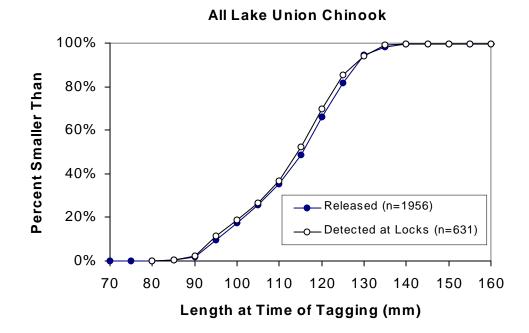


Figure 3-7. Cumulative frequency distributions of lengths of tagged and detected chinook salmon released at the Issaquah Hatchery (top) and UW Hatchery (bottom), 2001 Lake Washington GI study.



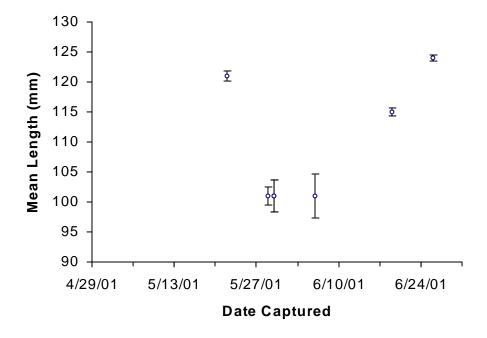
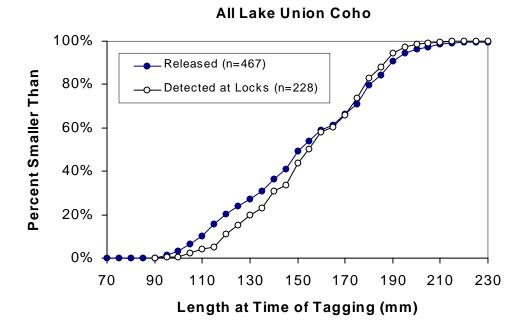


Figure 3-8. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in Lake Union and released near the Fremont Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



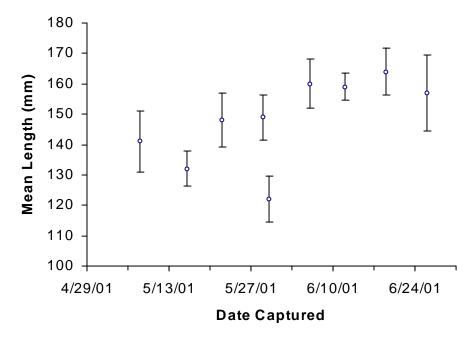
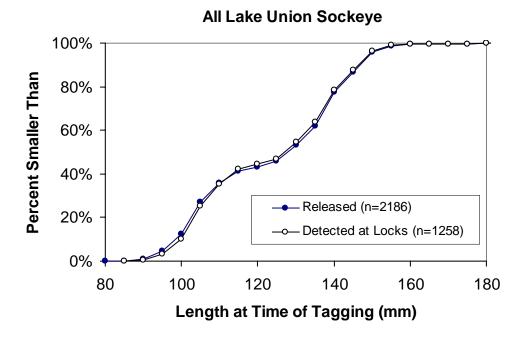


Figure 3-9. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in Lake Union and released near the Fremont Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



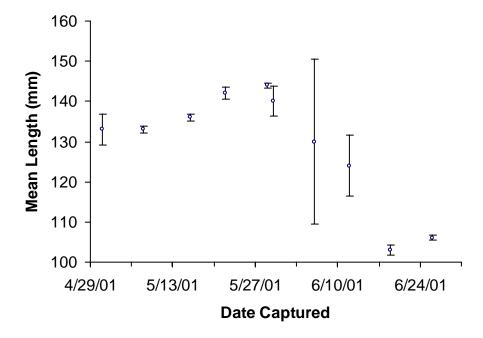
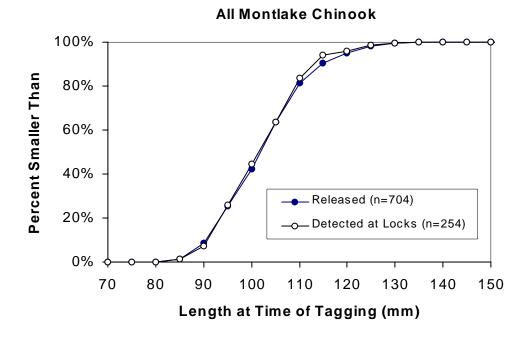


Figure 3-10. Cumulative frequency distributions of lengths of tagged and detected sockeye salmon caught in Lake Union and released near the Fremont Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



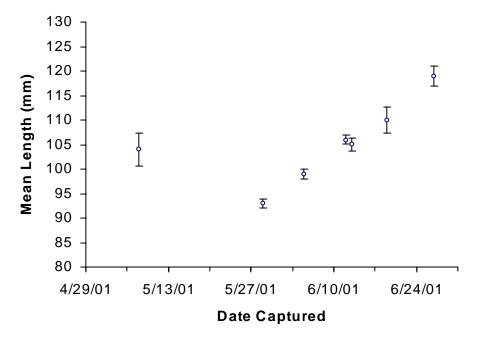
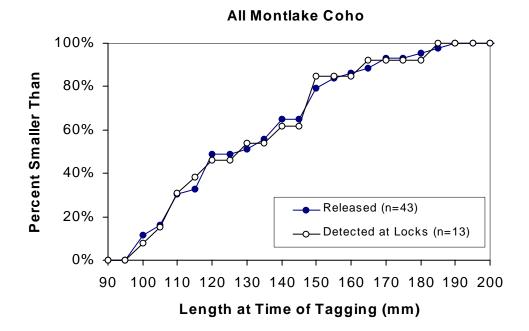


Figure 3-11. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in the vicinity of the Montlake Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



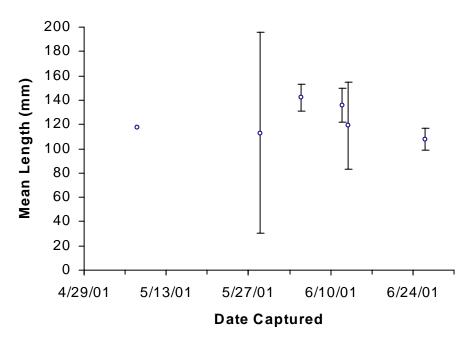
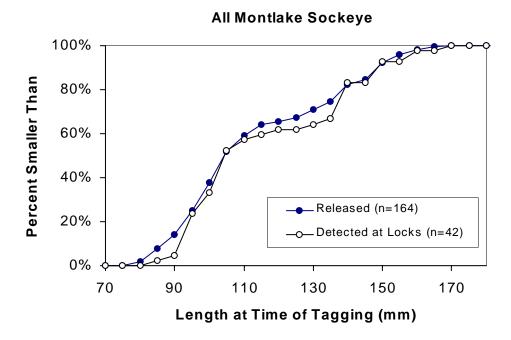


Figure 3-12. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in the vicinity of the Montlake Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



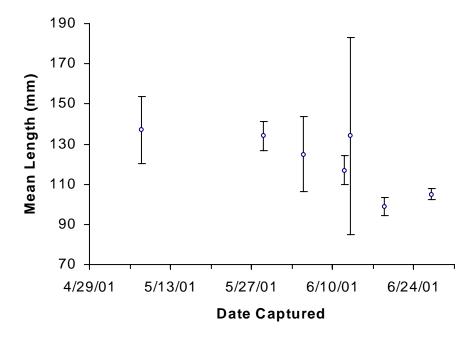
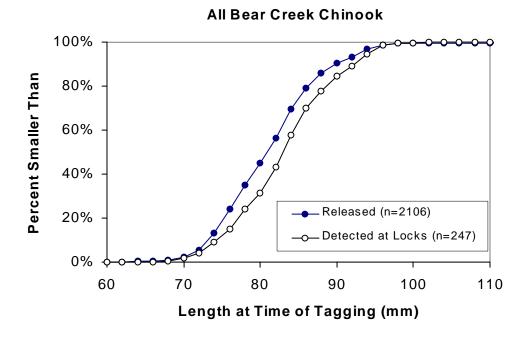


Figure 3-13. Cumulative frequency distributions of lengths of tagged and detected sockeye salmon caught in the vicinity of the Montlake Cut (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



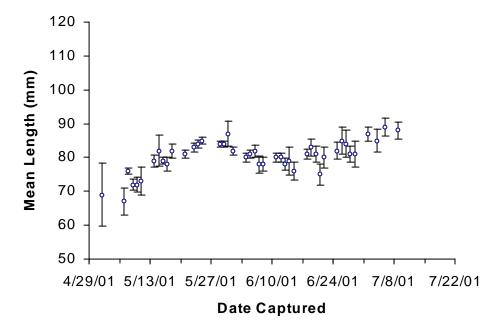
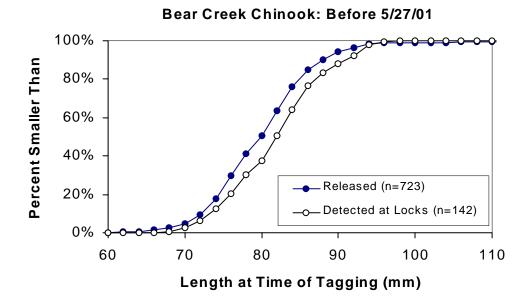


Figure 3-14. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



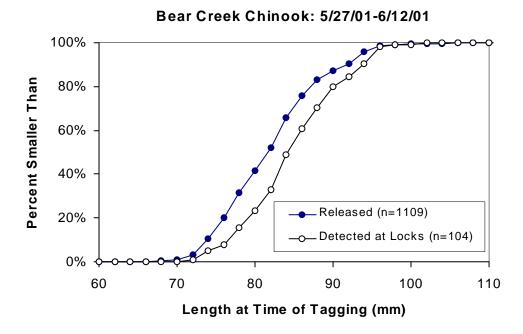


Figure 3-15. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in Bear Creek before 5/27/01 (top) and between 5/27/01 and 6/12/01 (bottom), 2001 Lake Washington GI study.

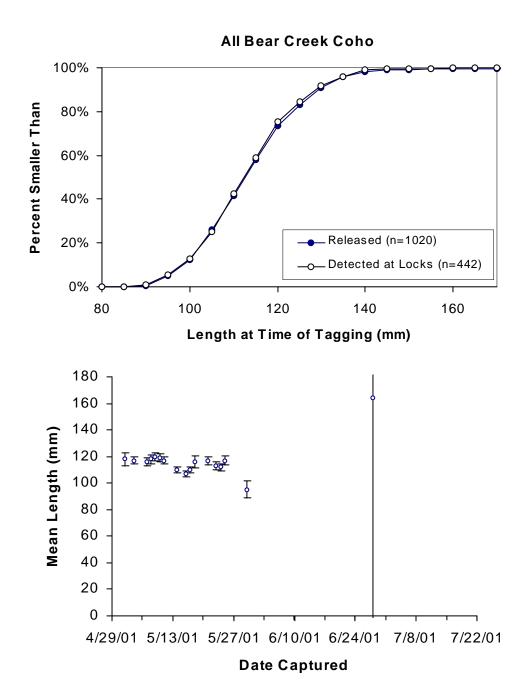
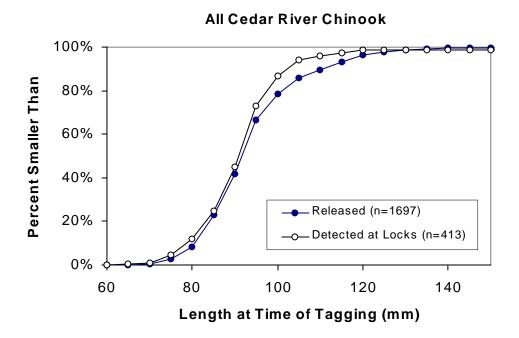


Figure 3-16. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.



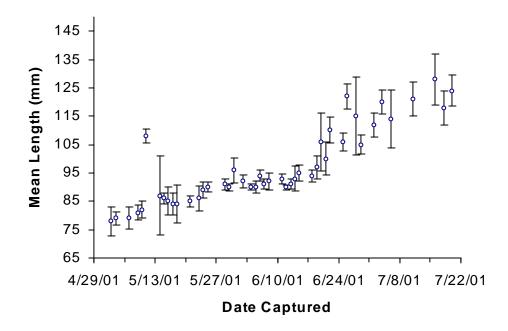
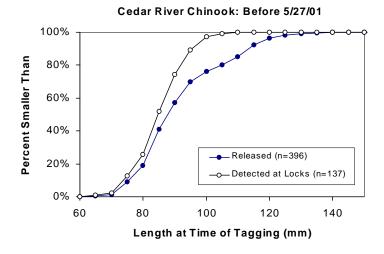
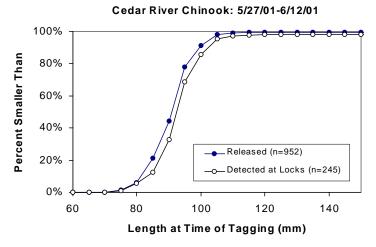


Figure 3-17. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.





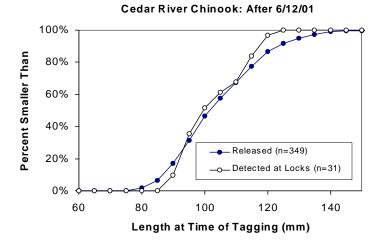
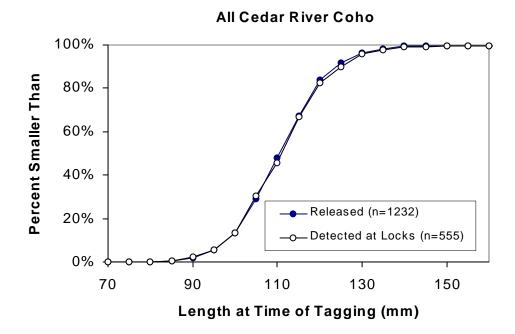


Figure 3-18. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in the Cedar River before 5/27/01 (top), between 5/27/01 and 6/12/01 (middle), and after 6/12/01 (bottom), 2001 Lake Washington GI study.



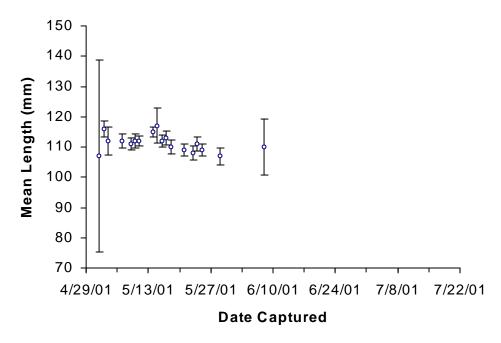


Figure 3-19. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2001 Lake Washington GI study.

There were a few exceptions, however, as well as a few cases of interesting variation observed in some of the fish length plots. In Lake Union, for example, the first group of chinook salmon were longer on average than subsequent groups, because there were a large number of the larger, UW hatchery fish present in the sample (Figure 3-8). A relatively large-sized group of chinook was also caught early in the outmigration season in the Montlake samples on May 8, 2001 (Figure 3-11). Fourteen of the nineteen fish captured were of hatchery origin, but when and where they were released was not determined (their capture occurred before fish were released from the Issaquah and UW hatcheries). Figures 3-10 and 3-13 suggest that there were also two distinct size classes of juvenile sockeye salmon that passed through the LWSC, where the earlier outmigrants were larger than the later ones.

Lengths of juvenile chinook captured in Bear Creek and the Cedar River appeared to exhibit more complicated patterns. Mean lengths increased in both streams until around May 27, 2001 (Figures 3-14, 3-17). Lengths then decreased in Bear Creek and remained similar in the Cedar River until around June 12, 2001, after which they increased again in both streams. Partitioning the length data into three groups divided by these two dates indicated different patterns existed in each stream. In total, Bear Creek chinook detected at the Locks were proportionally larger than fish from the total sample released (Figure 3-14; critical alpha = 0.02, 22 classes, ignoring distribution tail outliers). This pattern was also observed in 2000, and was similar for fish captured before May 27 and before June 12, 2001 (Figure 3-15). A similar pattern was not observed for coho salmon originating in Bear Creek (Figure 3-16). Conversely, Cedar River chinook detected at the Locks were proportionally smaller than fish from the total sample released (Figure 3-17; critical alpha = 0.006). When the data were partitioned into the three periods suggested by the length-time data in Figure 3-17, the pattern alternated over time. Of the chinook tagged and released before May 27, 2001, fish detected at the Locks were proportionally smaller than fish from the total sample released (Figure 3-18). Of the chinook tagged and released between May 27 and June 12, 2001, fish detected at the Locks were proportionally larger than fish from the total sample released (Figure 3-18). There did not appear to be a strong size-dependence on detection rate for chinook tagged and released after June 12, 2001 (Figure 3-18).

3.4 MIGRATION BEHAVIOR

The PIT tag data provided valuable information on arrival date and travel rate to the Locks from the different release locations. It is possible that the majority of the chinook run had passed through the Locks before the flumes were shut down, because the cumulative distributions of passage timing for each release group had pronounced asymptotes at their upper ends (Figure 3-

20). However, as will be discussed later, this may be in part an artifact of changes in passage behavior at the Locks, where later-arriving fish may have used the flumes less and chosen alternate routes (e.g., through the two locks).

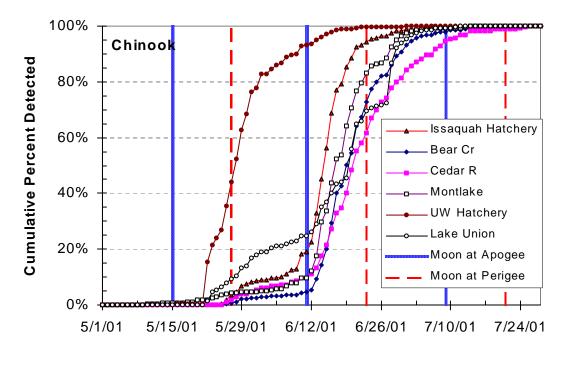
3.4.1 Migration Timing

As in 2000, sockeye salmon generally outmigrated first, followed by coho salmon, and then by chinook salmon. The UW hatchery chinook salmon exhibited a substantially different outmigration behavior from the other tagging groups, with the majority of fish passing the Locks early in the chinook outmigration season (Figure 3-20). All of the other chinook groups all passed through at about the same time. The same was true for the different groups of tagged coho salmon juveniles. There was an apparent difference in early timing between the tagged Lake Union and Montlake sockeye salmon, but as the outmigration season progressed the timing distributions became more similar (Figure 3-20). It is possible that the early difference may have been due to differences in sampling effectiveness at the two locations: sampling was initially less successful at the Montlake site (K. Fresh, personal communication).

A comparison of the passage timing data with lunar data suggested a strong connection existed between moon location relative to the earth and passage timing, particularly in the case of chinook and coho salmon. This connection appeared to be stronger than for moon phase, which is reasonable considering that light intensity at the Locks at night is strongly influenced by illumination and cloud cover. Specifically, passage through the Locks increased markedly for all three species within a day or two of the moon being at apogee (i.e., when it is farthest from the earth; Figure 3-20). Apogee occurred on May 15 and June 11, 2001. Passage was nearly complete by the time of the next apogee (July 9, 2001). This pattern was also observed in 2000, again most strongly in the case of chinook and coho salmon (Figure 3-21). A gravitational influence on passage timing is therefore suggested by the tunnel reader detection data. It is unknown if the fish detect this influence directly, or if the influence is manifest through small-magnitude tidal phenomena in Lake Washington and the LWSC.

3.4.2 Migration Rate

Average migration rates varied between the Issaquah and UW hatchery, Lake Union, Montlake, and tributary release groups. Table 3-2 lists the estimated minimum travel distances between the different release locations and the Locks, excluding possible detours. In the case of chinook and sockeye salmon, the number of days between release and detection generally reflected the



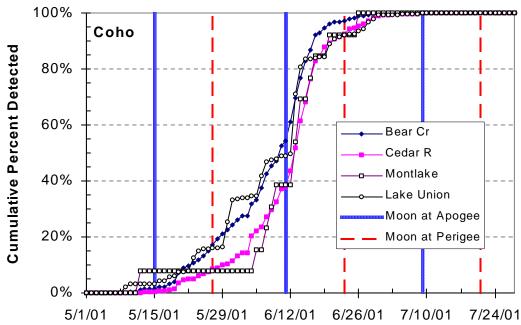


Figure 3-20. Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook, coho, and sockeye salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2001 Lake Washington GI study. The dates when the moon was at apogee and perigee are indicated by the vertical lines.

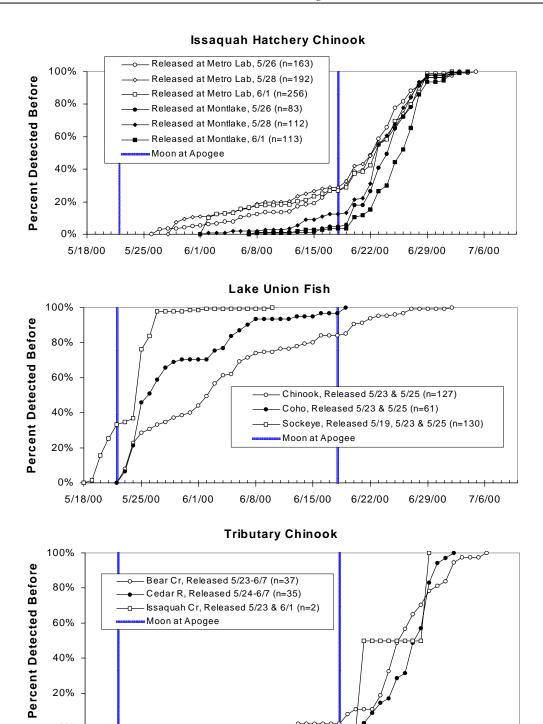


Figure 3-21. Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook, coho, and sockeye salmon that were detected as they passed the smolt flumes at the Locks, by date and release location, 2000 Lake Washington GI study. The dates when the moon was at apogee are indicated by the vertical lines.

6/8/00

6/15/00

6/22/00

6/29/00

7/6/00

5/18/00

5/25/00

6/1/00

distance traveled, with fish released farther away taking longer to reach and pass the Locks (Figure 3-22). The times for tributary coho salmon to reach and pass the Locks were more similar. However, most of the release groups, including tributary coho salmon, appeared to generally compensate for longer outmigration distances by traveling more rapidly on average (Figure 3-22). An exception was noted for coho salmon once they reached the LWSC, where they appeared to speed up their outmigration. Migration rates of chinook and tributary coho were generally 3 km/day or slower. Migration rates of coho and sockeye in the LWSC were faster, where approximately 80 percent of those fish moved at an average speed of 6 km/day or slower between release and detection (Figure 3-22). These and the other average migration rates reported here are all subject to uncertainty regarding the length of time spent in the vicinity of the Locks before passing through the flumes. For example, if tagged fish spend more than a few days near the Locks, their actual migration rate to the Locks would be faster than the rates estimated here.

Table 3-2. Minimum travel distances between release locations of PIT tagged fish and the Locks (see Section 2.6.2 for details on how distances were determined).

Release Location	Distance to Locks (km)
East of Fremont Bridge	5.1
Montlake Cut	10
Cedar River	39
Bear Creek	56
Issaquah Creek	76

The freshwater recapture data provided additional information on migration rates through different portions of the Lake Washington system (Table 3-3). Chinook originating from the Issaquah Hatchery appeared to migrate faster between the Hatchery and Lake Union than between Lake Union and the Locks (cf. Table 3-3 and Figure 3-22). Of the chinook originating from Bear Creek, the one fish caught in the vicinity of the Montlake Cut migrated faster than the other two recaptured in Lake Union, and appeared to have moved more slowly between the Montlake Cut and the Locks (Table 3-3). The two chinook recaptured in Lake Union migrated at a rate that was similar to that of the Bear Creek chinook in general between the smolt trap and the Locks (Figure 3-22). In contrast, chinook and coho tagged in the Cedar River and recaptured in Lake Union moved more quickly after recapture than before (Table 3-3).

Figures 3-23, 3-24, and 3-25 indicate that migration rates of individual chinook, coho, and sockeye salmon juveniles exhibit an increasing trend with time over the course of the

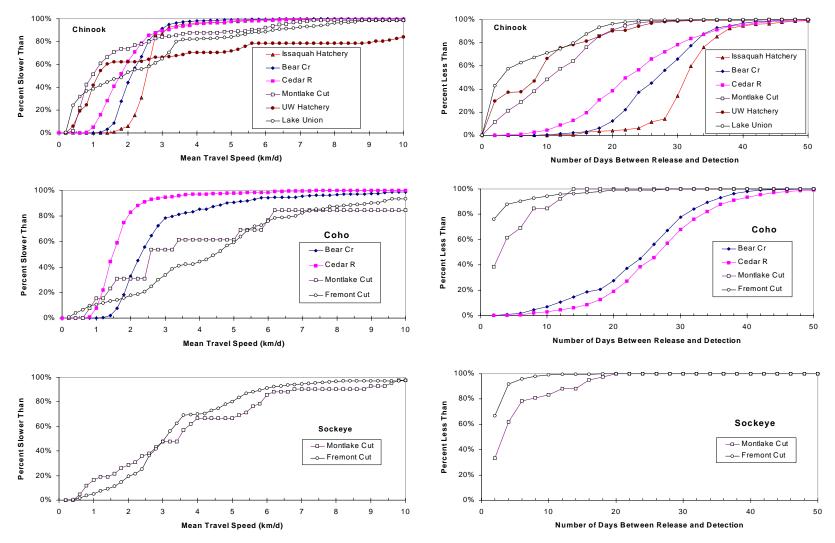


Figure 3-22. Cumulative frequency distributions of average travel speed (left) and time (right) of PIT tagged juvenile chinook (top), coho (middle), and sockeye salmon (bottom) detected in the smolt flumes at the Locks, by release location, 2001 Lake Washington GI study.

Table 3-3. Summary of 2001 freshwater PIT tag recapture data in the Lake Washington system (excluding large lock seining).

		Loc	ation of:	Migration Between Release and Recapture Locations						Subsequent Migration to Locks		
Species	Origin	Tagging/ Release	Recapture	Release Date	Days to Recapture	Approx. Travel Distance (km)	Average Migration Rate (km/d)	Average Growth Rate (mm/d)	Days	Average Migration Rate (km/d)		
Chinook	Н	Issaquah Hatchery	Lake Union	05/15/01	14.3	73	5.1	0.7	12.0	0.5		
	Н	Issaquah Hatchery	Lake Union	05/15/01	14.3	73	5.1	0.6	Not De	etected at Locks		
	Н	Issaquah Hatchery	Lake Union	05/15/01	28.0	73	2.6	0.9	Not De	etected at Locks		
	Н	Issaquah Hatchery	Sammamish R near Redmond	05/15/01	6.6	24	3.7	-		ld Reader Failed; No. Unknown		
	Н	Issaquah Hatchery	Sammamish R near L. Bear Cr	05/15/01	8.7	33	3.8	0.6	Not Do	etected at Locks		
	W	Bear Creek	Montlake Cut	05/15/01	14.0	45	3.2	1.1	18.8	0.6		
	W	Bear Creek	Lake Union	05/30/01	20.3	50	2.5	1.5	Not De	etected at Locks		
	W	Bear Creek	Lake Union	05/25/01	25.2	50	2.0	0.5	Mortality	During Handling		
	\mathbf{W}^{1}	Cedar River	Lake Union	05/15/01	14.1	33	2.3	0.7	1.7	3.8		
	\mathbf{W}^{1}	Cedar River	Lake Union	06/11/01	8.4	33	3.9	1.3	0.6	10.9		
	W	Cedar River	Cedar River	05/31/01	1.6	0	-	-	23.3	1.7		
	W	Cedar River	Lake Union	05/25/01	32.4	33	1.0	1.2	Not De	etected at Locks		
	Н	UW Hatchery	Lake Union	05/21/01	0.8	3.5	4.4	0.5	Not De	etected at Locks		
	Н	Lake Union	Lake Union	06/12/01	7.0	0	-	-	Not De	etected at Locks		
Coho	W	Cedar River	Lake Union	05/03/01	26.6	33	1.2	1.1	1.1	5.9		
	W	Cedar River	Lake Union	05/21/01	22.3	33	1.5	1.4	0.7	8.4		
	W	Cedar River	Lake Union	05/23/01	21.0	33	1.6	1.1	0.1	48.3		
	W	Bear Creek	Bear Creek	05/09/01	1.2	0	-	-	33.0	1.7		
	W	Bear Creek	Bear Creek	05/23/01	1.0	0	-	-	24.2	2.3		
	W	Cedar River	Montlake Cut	05/21/01	22.4	28	1.3	1.3	Not De	etected at Locks		

⁻ Called "Hatchery" in Lake Union Tagging File

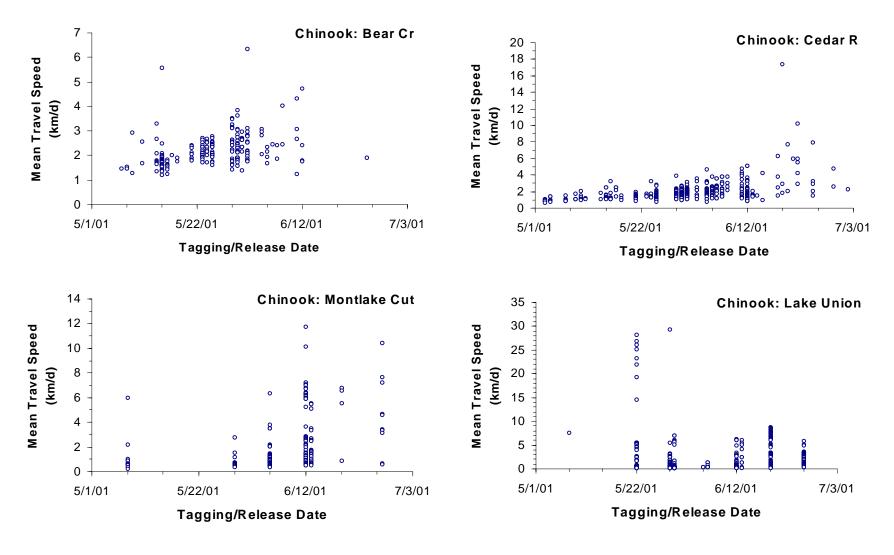


Figure 3-23. Scatterplot of mean travel speed of individual PIT tagged juvenile chinook salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2001 Lake Washington GI study.

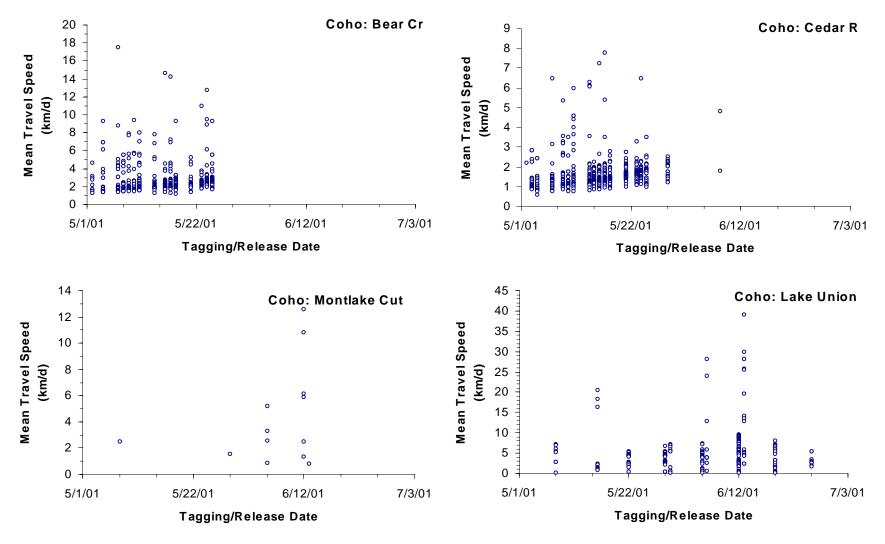


Figure 3-24. Scatterplot of mean travel speed of individual PIT tagged juvenile coho salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2001 Lake Washington GI study.

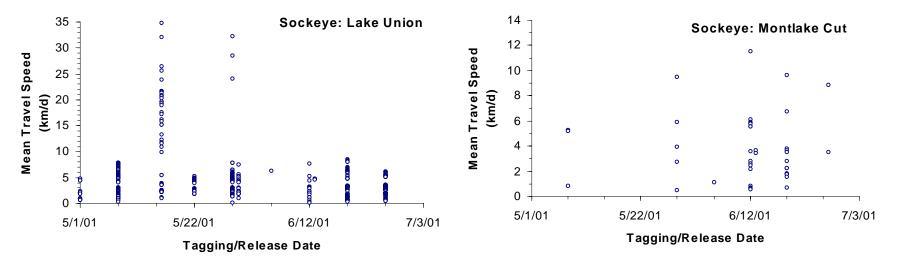


Figure 3-25. Scatterplot of mean travel speed of individual PIT tagged juvenile sockeye salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2001 Lake Washington GI study.

outmigration season, particularly in the case of tributary fish. There is also a trend evident in the PIT tagged fish caught and released in the vicinity of the Montlake Cut, but a similar trend is not clearly seen in the case of fish caught in Lake Union and released near the Fremont Cut. These results suggest that juvenile salmon in the Lake Washington system speed up their migration slightly as the end of the passage season approaches.

The cumulative frequency distributions of numbers of juvenile salmon tagged and detected at the flumes can also be used to describe travel times for the different release groups (Figures 3-26, 3-27, and 3-28). In general, the distributions indicate that chinook salmon originating in Bear Creek, the Cedar River, in the Montlake Cut, and in Lake Union took approximately 4 weeks, 3 weeks, 1 week, and less than 1 week, respectively, to reach and pass the smolt flumes (Figure 3-26). Coho salmon from both Bear Creek and the Cedar River both took approximately 4 weeks, whereas once fish reached the LWSC, they generally took less than a week to reach and pass the smolt flumes (Figure 3-27). Sockeye salmon exhibit a similar migration rate to coho in the LWSC (Figure 3-28).

3.5 PASSAGE BEHAVIOR AT LOCKS

The PIT tag data also provided valuable information on the daily timing and routes of downstream passage at the Locks.

3.5.1 Diurnal Variation in Passage Timing

As in 2000, a behavioral pattern that was common to all release groups was the predominance of passage during daylight hours (Figure 3-29). The pattern was again most striking for tagged sockeye, of which a negligible number passed during nighttime hours. Passage rates increased markedly beginning around 5:00 am. Moreover, there were generally two pronounced peak passage times: between approximately 6:00 am and 9:00 am, and between 11:00 am and 2:00 pm (Figure 3-29). Each species exhibited a general passage timing distribution that was similar among release groups (Figure 3-30). The pattern became more pronounced during the latter two weeks of June than before that time period for chinook and sockeye tagged and released in Lake Union, however, where proportionally more fish passed earlier in the day after June 11, 2001, when the moon was at apogee, than before (Figure 3-31). These results generally stand in contrast to data collected for the Columbia River system, where passage at hydropower facilities has been noted to occur predominantly during nighttime hours (e.g., Brege et al. 1996).

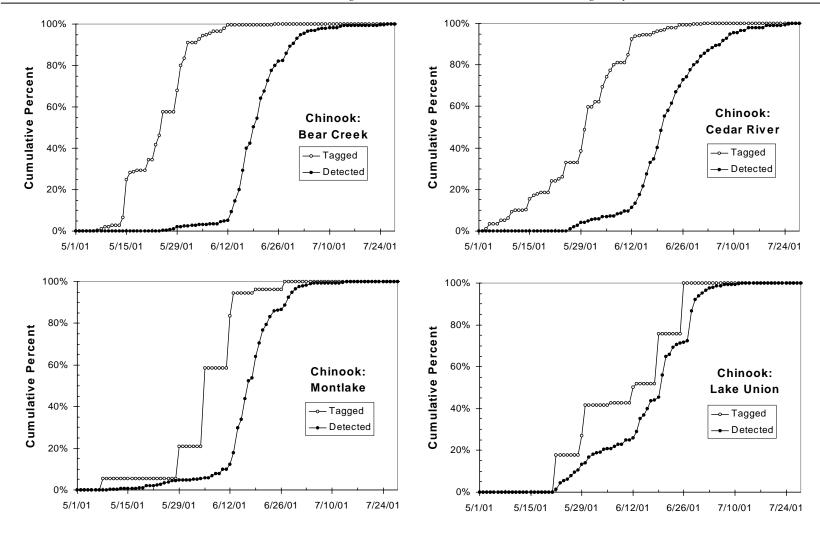


Figure 3-26. Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2001 Lake Washington GI study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt flumes.

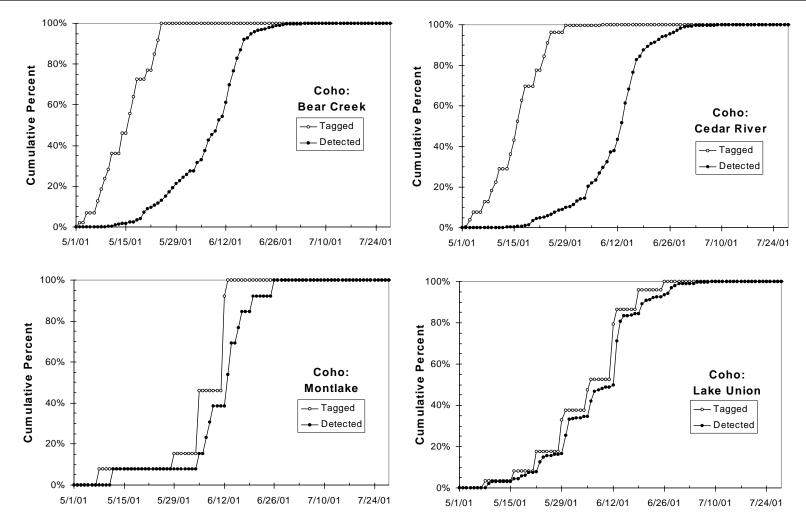


Figure 3-27. Cumulative frequency distributions of the numbers of PIT tagged juvenile coho salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2001 Lake Washington GI study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt flumes.

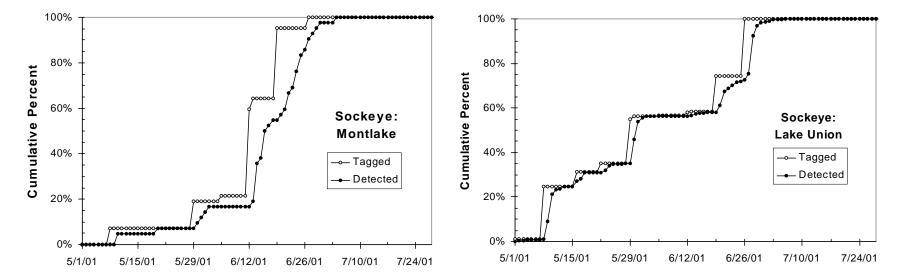
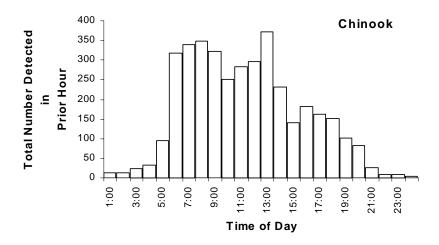
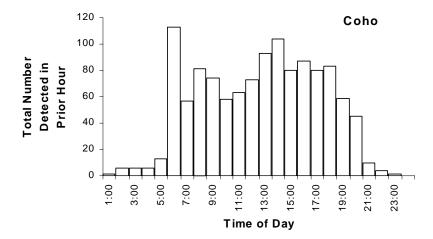


Figure 3-28. Cumulative frequency distributions of the numbers of PIT tagged juvenile sockeye salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2001 Lake Washington GI study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt flumes.





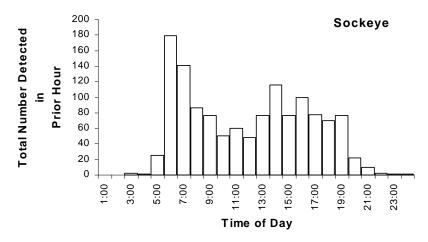
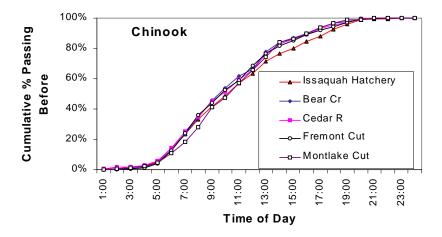
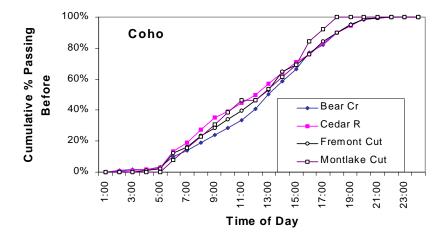


Figure 3-29. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile salmon, 2001 Lake Washington GI study. All release groups for each salmon species are represented.





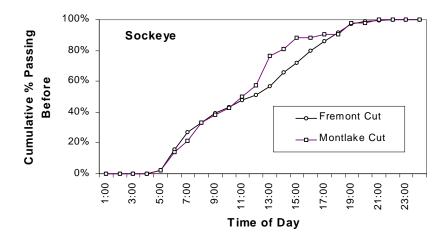
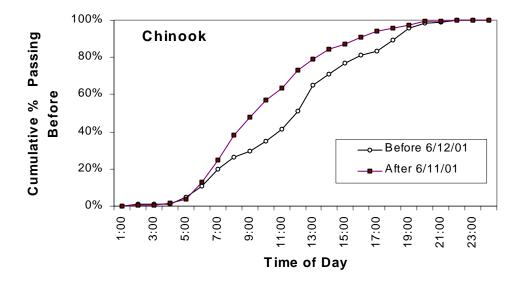


Figure 3-30. Cumulative frequency distributions of the diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile salmon, by release location, 2001 Lake Washington GI study.



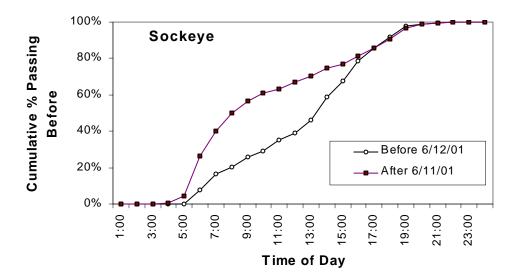


Figure 3-31. Cumulative frequency distributions of the diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile chinook and sockeye salmon caught in Lake Union and released near the Fremont Cut, 2001 Lake Washington GI study. The data are partitioned according to whether they were detected before or after June 11, 2001 when the moon was at apogee.

3.5.2 Routes Through the Locks

Of the PIT tagged fish that passed through the smolt flumes, the majority passed through the two largest flumes when all four were operating during the time of peak chinook passage (June 10 to through June 17, 2001; see Figure 3-1). However, there was not as clear a preference for a specific spillway gate by all three species as in 2000, when proportionally more tagged fish passed through the Flumes 5C and 5B. In 2001, 63%, 48%, and 51% of detected chinook, coho, and sockeye, respectively, passed through gate 5 when all four flumes were operational, suggesting that only chinook salmon juveniles may have exhibited a partial preference that year.

Figure 3-32 depicts the possible passage routes through the Locks. As in 2000, the PIT tag data confirmed that recycling occurred through the Locks as indicated in the figure. For example, 91 PIT tagged chinook and 7 coho salmon were detected twice by the tunnel readers (Figure 3-33). They therefore had to have migrated back upstream through either the large or small lock. Several fish caught during seining in the large lock also passed through the tunnel detectors either prior or subsequent to capture (Table 3-4). With the exception of calibration test chinook, held at the Metro Laboratory prior to release, all but one coho juvenile exhibited a distribution in Figure 3-33 that was similar to that observed in the 2000 study. The behavior of the calibration test chinook was atypical of naturally produced fish and Issaquah Hatchery releases, possibly because they were held in chilled water, and were released directly into the flumes. As in the 2000 study, the intervening time between first and second detection shortened as the outmigration season progressed. There were no fish other than the calibration test chinook that were observed to recycle during the last two weeks of June 2001 when chinook passage was peaking (Figure 3-33).

The UW hatchery chinook exhibited the strongest recycling behavior of all the groups. This was manifest by 29 PIT tagged fish from that group that recycled more than twice (Figure 3-34). No fish from any of the other groups was observed to have exhibited this behavior. One of the UW Hatchery chinook recycled seven times. This difference in behavior from the other study fish may reflect their early release from the hatchery and rapid arrival at the Locks compared to the other test groups.

In summary, the PIT tag data indicate that a strong seasonal influence on outmigration existed in the LWSC, and that some chinook juveniles lingered in the upstream and downstream vicinity of the Locks before most actively making the transition to saltwater during the last two weeks of June 2001. There was no relation of recycling time between detections in the flumes to release group or size of fish at time of tagging.

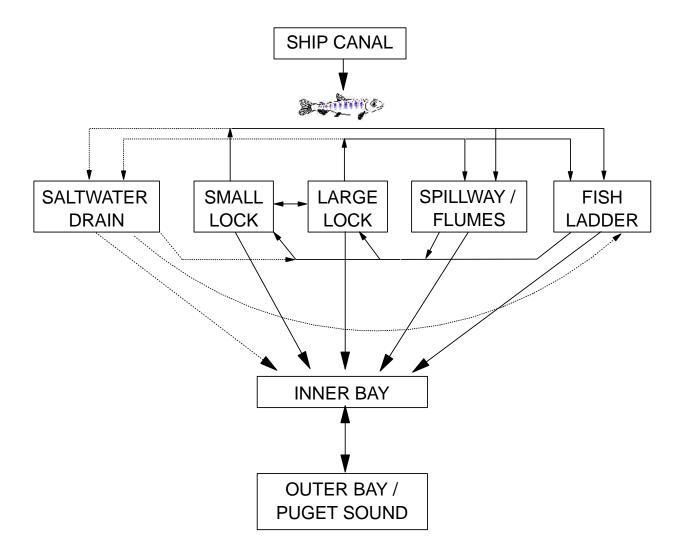


Figure 3-32. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the saltwater beaches located below. The routes are indicated for fish after they have first encountered the Locks and have entered one of the five structural facilities indicated. For example, a fish entering the smolt flumes may subsequently move back upstream through either the small or large lock, and return downstream through any of the five routes. Alternatively, the fish may migrate directly to saltwater. The route through the saltwater drain is thought to be of lesser importance to smolt passage than the other four routes and is thus indicated by the dashed lines.

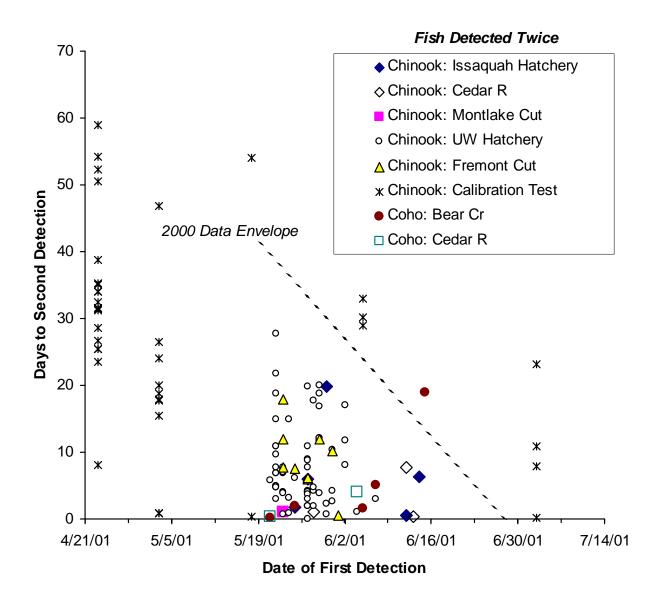


Figure 3-33. Recycling times of PIT tagged juvenile chinook and coho salmon passing downstream twice through the smolt flumes at the Locks, 2001 Lake Washington GI study. The upper data envelope from the 2000 study is indicated by the diagonal dashed line.

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

Species	Release Location	Release Date	Tag No.	Date	Lock Time Captured	Flui Date Detected	mes Time Detected	Hatchery/ Natural	Comments
Chinook	Tunnel	5/3/01	3D9.1BF1125A6E	5/24/01		Not Detec	ted Again	Н	Tags Not Recorded on Data Sheets
	Reader	5/18/01	3D9.1BF113314F	5/24/01		Not Detec	ted Again	Н	Tags Not Recorded on Data Sheets
	Calibration	5/18/01	3D9.1BF113D0AE	6/7/01	11:00	Not Detec	ted Again	Н	
	Testing	6/5/01	3D9.1BF113C058	6/20/01	9:30	Not Detec	ted Again	Н	
		7/3/01	3D9.1BF1129E67	7/11/01	16:30	7/14/01	7:24:26	Н	
		7/3/01	3D9.1BF111D5B4	7/11/01	16:30	Not Detec	ted Again	Н	
	Issaquah	5/15/01	3D9.1BF113BC24	6/6/01	11:30	Not De	etected	Н	
	Hatchery	5/15/01	3D9.1BF113CD32	6/7/01	12:30	Not De	Not Detected		
	"	5/15/01	3D9.1BF113C623	6/13/01	17:30	Not De	etected	Н	
	"	5/15/01	3D9.1BF1135491	6/14/01	15:30	Not De	etected	Н	
	"	5/15/01	3D9.1BF11396D0	6/14/01	15:30	Not De	etected	Н	
	"	5/15/01	3D9.1BF112A28E	6/14/01	15:30	Not De	etected	Н	
	"	5/15/01	3D9.1BF113C142	6/14/01	17:30	Not De	etected	Н	
	"	5/15/01	3D9.1BF1133201	6/20/01	9:30	Not De	etected	Н	
	Montlake	5/29/01	3D9.1BF11110B7	6/14/01	16:30	6/14/01	10:36:14	Н	
	Lake Union	5/22/01	3D9.1BF1112F1C	5/23/01	13:00	Not De	etected	Н	
	"	5/22/01	3D9.1BF10D8A10	BF10D8A10 6/6/01 10:00		Not De	etected	Н	
	"	5/22/01	3D9.1BF1107BA5	6/6/01	11:30	Not Detected Not Detected		Н	
	"	6/19/01	3D9.1BF0E295C7	6/20/01	11:30			N	
	"	6/19/01	3D9.1BF10CDA56	6/20/01	11:30	Not De	etected	N	
	"	6/19/01	3D9.1BF0DD3858	6/21/01	9:30	Not De	etected	Н	

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

Release Species Location		Release Date	Release Date	Tag No.	Date	e Lock Time Captured	Flu Date Detected	mes Time Detected	Hatchery/ Natural	Comments
Брестев	"	6/19/01	3D9.1BF0E16B29	6/21/01	9:30	Not De		Н	Comments	
	"	6/19/01	3D9.1BF0E14960	7/11/01	15:30	Not De	etected	Н		
	UW Hatchery	5/21/01	3D9.1BF11344AA	5/23/01	10:00	5/31/01	19:52:11	Н	First Set; Assume Time	
	"	5/21/01	3D9.1BF1125A0E	6/6/01	10:00	Not De	etected	Н		
	"	5/21/01	3D9.1BF113066D	6/6/01	11:30	5/23/01	15:17:10	Н		
	"	5/21/01	3D9.1BF1123CF4	6/6/01	11:30	5/22/01	16:52:01	Н	Recycling	
	"		11			6/5/01	11:00:18	Н	Recycling	
	"		11			6/15/01	9:47:44	Н	Recycling	
	"	5/21/01	3D9.1BF11252FB	6/6/01	11:30	Not De	etected	Н		
	"	5/21/01	3D9.1BF1134723	6/6/01	11:30	5/23/01	16:55:59	Н	Recycling	
	"		"			5/26/28		Н	Recycling	
	"	5/21/01	3D9.1BF1130FA0	6/6/01	11:30	5/25/01	17:59:52	Н		
	"	5/21/01	3D9.1BF112AD6E	6/7/01	12:30	Not De	etected	Н		
	"	5/21/01	3D9.1BF113ACC1	6/7/01	12:30	Not De	etected	Н		
	"	5/21/01	3D9.1BF11356CD	6/14/01	16:30	5/28/01	12:10:33	Н		
	"	5/21/01	3D9.1BF112477F	6/14/01	16:30	Not De	etected	Н		
	"	5/21/01	3D9.1BF112CA4A	6/14/01	16:30	5/22/01	12:18:18	Н	Recycling	
	"		"			6/4/01	8:52:36	Н	Recycling	
	"		11			6/5/01	13:42:14	Н	Recycling	
	"		"			6/6/01	10:45:48	Н	Recycling	

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

	ъ.			Large		Flumes		TT () (
Species	Release Location	Release Date	Tag No.	Date Captured	Time Captured	Date Detected	Time Detected	Hatchery/ Natural	Comments
	"		11			6/13/01	6:33:10	Н	Recycling
Coho	Bear Cr	5/17/01	3D9.1BF1114ADA	6/6/01	10:00	Not De	etected	N	
	"	5/25/01	3D9.1BF111298C	6/14/01	15:30	Not De	etected	N	
	"	5/9/01	3D9.1BF1132C9C	6/14/01	16:30	6/7/01	15:51:48	N	
	Cedar R	5/11/01	3D9.1BF113BC8F	6/7/01	11:00	Not De	etected	N	
	"	5/15/01	3D9.1BF11309F1	6/14/01	18:30	Not De	etected	N	
	Montlake	6/5/01	3D9.1BF10D1D0D	6/7/01	10:00	Not De	Not Detected		First Set; Assume Time
	Lake Union	6/5/01	3D9.1BF0DD9032	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF0DD903E	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF0E3B39E	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF1114AF4	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF0DDA333	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF1020DFA	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF10D8CAA	6/6/01	10:00	Not De	etected	Н	
	"	6/5/01	3D9.1BF1025B2E	6/6/01	11:30	Not Detected		Н	
	"	6/6/01	3D9.1BF0E24030	6/7/01	11:00	Not Detected		Н	
	"	6/6/01	3D9.1BF111AED2	6/7/01	12:30	Not De	etected	N	
	"	6/5/01	3D9.1BF10D75B7	6/7/01	14:00	6/6/01	13:03:13	N	

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

				Large	Lock	Flumes			
Species	Release Location	Release Date	Tag No.	Date Captured	Time Captured	Date Detected	Time Detected	Hatchery/ Natural	Comments
Sockeye	Lake Union	5/8/01	3D9.1BF1112EBF	5/9/01	13:30	Not De	etected	N	
	"	5/8/01	3D9.1BF1113627	5/9/01	13:30	Not De	Not Detected		
	"	5/8/01	3D9.1BF11145DB	5/9/01	13:30	Not De	Not Detected		
	"	5/8/01	3D9.1BF11106AB	5/9/01	13:30	Not De	etected	N	
	"	6/5/01	3D9.1BF10F0203	6/6/01	10:00	Not De	etected	N	
	"	6/5/01	3D9.1BF10B1E27	6/6/01	10:00	Not Detected		N	
	"	6/5/01	3D9.1BF1020302	6/7/01	10:00	Not Detected		N	First Set; Assume Time
	"	6/12/01	3D9.1BF0E143A4	6/21/01	11:30	Not De	etected	N	

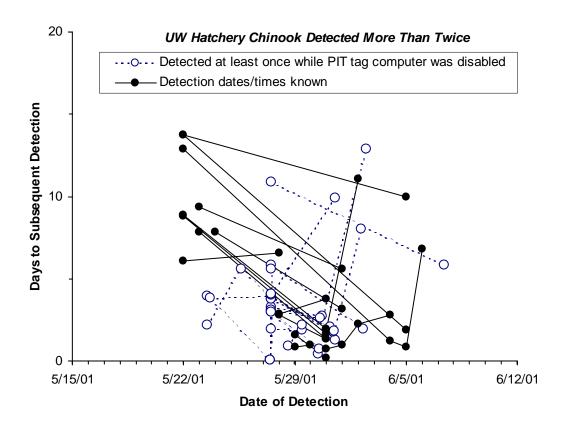


Figure 3-34. Recycling times of PIT tagged juvenile chinook salmon from the UW Hatchery passing downstream more than two times through the smolt flumes at the Locks, 2001 Lake Washington GI study. The open circles represent fish that were detected during times when the PIT tag computer was disabled (see Figure 3-1), and thus the recycling time is approximate to within a day for those fish.

3.5.3 Influence of Lock Operations on Passage Through Flumes

Figures 3-35 and 3-36 indicate that there was a tendency for PIT tagged fish to pass through the flumes at a higher rate during the fill period than during the between-fill period. It was not possible to determine if this was related to diurnal differences in behavior near the large lock culverts (Johnson et al. 2001) as the majority of PIT tag detections occurred during daylight hours. To evaluate this statistically, the data in the figures were filtered and cases identified where fish were detected during consecutive fill and between-fill periods. A ratio was calculated of the passage rate during fill to the passage rate during the subsequent between-fill period. Two-tailed t-tests of the ratio indicated that it was significantly greater than 1.0 on average (p<0.05). In other words, the mean passage rates through the flumes were significantly greater during the fill period than afterwards for both the small and the large locks.

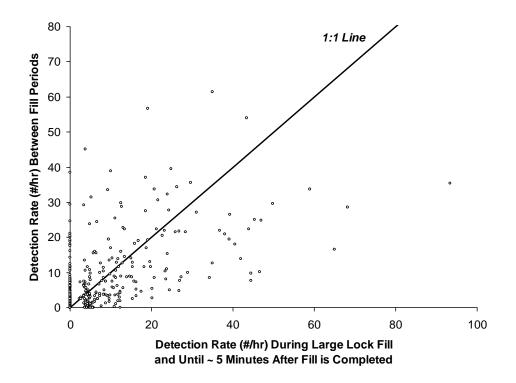
3.6 ESTUARINE BEHAVIOR

Beach sampling was conducted at the railroad bridge and downstream where salinity appears to be usually equal to or greater than 15 ppt. Captures of PIT tagged fish in the beach seine samples thus provide temporal and spatial information regarding the transition to saltwater. Table 3-5 summarizes the tagging and capture histories of PIT tagged fish caught in beach seine samples that were collected below the Locks. There was a large fraction of the PIT tagged fish that was caught in the inner bay within a few days of detection in the smolt flumes. One chinook salmon juvenile was recaptured during beach seining near the railroad bridge within 10 minutes of having passed through the flumes. A coho juvenile was also recaptured at that location within 45 minutes of passage (Table 3-5).

One of the calibration test chinook was captured at the railroad bridge, and later passed through the flumes again in mid-July 2001 (Table 3-5). However, as described previously, this unique behavior may not necessarily be representative of other chinook salmon juveniles passing through the LWSC and the Locks.

3.7 SURVIVAL ESTIMATES

The PIT tag data were used to estimate relative differences in survival over discrete segments of the outmigration route in the LWSC and the Lake Washington system. However, the precision of the results was adversely influenced by the variation in tunnel reader detection efficiency, and because the proportion using the flumes could not be estimated consistently or with satisfactory precision as described in Section 2.6.5. Only two estimates could be made of the proportion using the flumes, based on the recapture data below the Locks: 39% for Lake Union coho



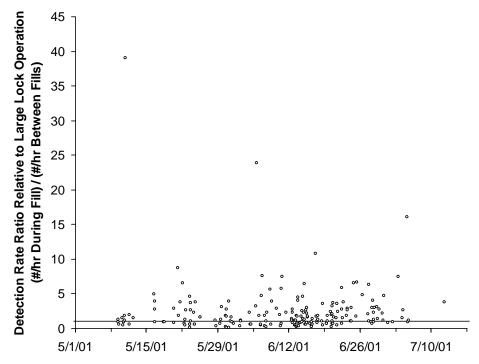
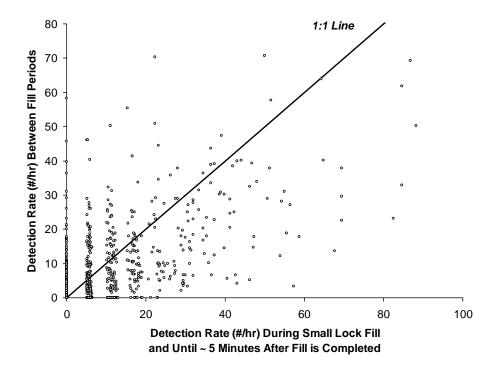


Figure 3-35. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the large lock and until the next fill, 2001 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.



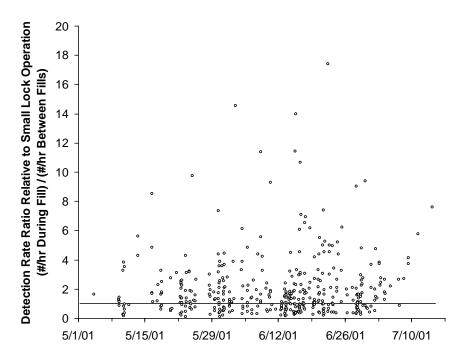


Figure 3-36. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2001 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

Table 3-5. Summary of Beach Seine Recapture Data Below Locks, Lake Washington GI 2001 PIT Tag Study

					Saltwater					Flumes			
Species	Release Location	Release Date	Tag No.	Capture Location	Date Captured	Time Captured	Salinity (ppt)	Days in Saltwater	Date Detected	Time Detected	Hatchery Natural	Comments	
Chinook	Tunnel	Same	3D9.1BF1131777	Groundswell	5/31/01	13:00	-	38.1	4/23/01	10:37	Н		
	Reader	as	3D9.1BF113C8B5	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:36	Н	Capture Date/Location Assumed Capture Date/Location	
	Calibration	Date	3D9.1BF11325BE	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:36	Н	Assumed	
	Testing	Detected	"	Railroad	6/18/01	14:00	15.9	-	Saltwate	r Recap	Н		
	"	in	3D9.1BF1276EE5	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:34	Н	Capture Date/Location Assumed	
	"	Flumes	3D9.1BF1276922	Railroad	6/18/01	14:00	15.9	31.2	5/18/01	9:53	Н		
	"	"	11		Subsequer	nt Recycling	Through	Freshwater	7/11/01	9:39	Н		
	"	"	3D9.1BF113C19D	Railroad	6/18/01	14:00	15.9	13.2	6/5/01	9:55	Н		
	"	"	"	Railroad	6/18/01	21:30	-	-	Saltwate	r Recap	Н		
	"	"	3D9.1BF113CE28	Railroad	6/18/01	14:00	15.9	13.2	6/5/01	9:38	Н		
	"	"	3D9.1BF113D0F4	Railroad	6/18/01	14:30	20.2	13.2	6/5/01	9:55	Н		
	"	"	3D9.1BF113C7A3	Railroad	6/18/01	14:30	20.2	13.2	6/5/01	9:35	Н		
	"	"	3D9.1BF113D08C	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:56	Н		
	"	"	3D9.1BF113BFD5	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:57	Н		
	"	"	3D9.1BF113D710	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:43	Н	Capture Date/Location Assumed	
	"	"	3D9.1BF113B4D2	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:37	Н		
	"	"	3D9.1BF1137C5A	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:45	Н		
	"	"	**	Railroad	6/19/01	21:00	17.0	-	Saltwate	r Recap	Н		
	"	"	3D9.1BF11376DD	Coke Machine	6/19/01	21:30	21.5	14.5	6/5/01	10:03	Н		
	"	"	3D9.1BF113C5DF	Coke Machine	6/19/01	21:30	21.5	14.5	6/5/01	9:38	Н		
	"	"	3D9.1BF11381E5	Railroad	6/19/01	22:30	-	14.5	6/5/01	10:11	Н		

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Table 3-5. Summary of Beach Seine Recapture Data Below Locks, Lake Washington GI 2001 PIT Tag Study

					Saltwater Flumes							
Species	Release Location	Release Date	Tag No.	Capture Location	Date Captured	Time Captured	Salinity (ppt)	Days in Saltwater	Date Detected	Time Detected	Hatchery/ Natural	Comments
	"	"	3D9.1BF113CA30	Railroad	6/20/01	11:30	-	15.1	6/5/01	9:50	Н	
	"	"	3D9.1BF113C328	Railroad	6/20/01	11:30	-	15.1	6/5/01	10:09	Н	
	"	"	3D9.1BF113C179	Railroad	6/20/01	21:00	16.8	15.5	6/5/01	9:44	Н	
	"	"	3D9.1BF113B40E	Middle Beach	6/22/01	1:00	-	16.6	6/5/01	9:36	Н	
	Bear Cr	5/25/01	3D9.1BF10CAC75	Railroad	6/18/01	14:00	15.9	0.8	6/17/01	19:57	N	
	"	5/30/01	3D9.1BF1107FA4	Railroad	6/19/01	10:00	-	0.0	6/19/01	9:53	N	
	Lake Union	5/30/01	3D9.1BF11125A4 3D9.1BF10D7AB	Statue of Liberty	6/18/01	10:30	22.9	2.9	6/15/01	12:27	Н	
	"	5/30/01	1	Piling Beach	6/22/01	12:30	-	4.0	6/18/01	13:11	Н	
	Montlake	6/5/01	3D9.1BF0FF3E85	Dolphin 8	6/18/01	10:00	27.8	-	Not De	tected	Н	
_	"	6/12/01	3D9.1BF0E6123B	Railroad	6/21/01	23:30	-	-	Not De	tected	N	
	UW Hatchery	5/21/01	3D9.1BF113901E	Statue of Liberty	6/6/01	13:45	-	6.1	5/31/01	12:02	Н	Capture Date/Location Assumed
Coho	Bear Cr	5/9/01	3D9.1BF1133781	Groundswell	6/13/01	10:30	-	0.7	6/12/01	18:19	N	
	"	5/16/01	3D9.1BF1112F0C	Groundswell	6/20/01	22:30	20.5	8.3	6/12/01	14:39	N	
	Cedar R	5/18/01	3D9.1BF1114BCC	Railroad	6/19/01	10:45	-	0.03	6/19/01	10:02	N	
	"	5/17/01	3D9.1BF11144E0	Groundswell	6/20/01	14:00	-	6.4	6/14/01	4:22	N	
	Lake Union	5/22/01	3D9.1BF114E014	Railroad	6/18/01	23:30	-	-	Not De	tected	Н	Grew From 112 to 120 mm in 27d

released the week of May 21, 2001, and 82% for Montlake chinook released the weeks of June 4 and 11, 2001 (determined using program RELEASE; Burnham et al. 1987; model H2p; see output in Appendix C). In addition, the proportion using the flumes may not have been constant over the passage season.

This last point is suggested by the PIT tag data, where the tunnel reader detection rate computed for most release groups decreased over time (Figures 3-37, 3-38, and 3-39). This trend was strongest for chinook (Figure 3-37), which outmigrated the latest, and weakest for sockeye (Figure 3-39), which outmigrated the earliest during the passage season. Average weekly detection rates (after adjusting for detection efficiency) were on the order of 20%, 50%, and 70% for chinook released in Bear Creek, the Cedar River, and the Montlake Cut, respectively, in early May (Figure 3-40). By late June to early July, they were near zero. In contrast, the detection rate for chinook caught in Lake Union and released near the Fremont Cut was more steady, holding around 30% to 40%.

Coho salmon detection rates followed a similar but less prominent trend, probably because the majority had outmigrated before the chinook detection rates dropped substantially (Figure 3-41). However, naturally reared coho salmon caught in Lake Union showed a stronger declining trend than their chinook counterparts, whereas the hatchery fish in those samples were detected at a steadier rate. Sockeye salmon caught in the vicinity of the Montlake Cut also showed a declining trend, whereas sockeye caught in Lake Union were associated with a relatively level, albeit more variable, trend (Figure 3-42). Sample sizes for steelhead were generally too small to infer a trend (Figure 3-42).

Given the apparent temporal trend in detection rate and the small number of samples from which the proportion using the flumes could be estimated from (poorly, to boot), it was not possible to estimate absolute survivals of the release groups to the Locks, as indicated in Section 2.6.5. However, the PIT tag data indicated some interesting results regarding survival along different portions of the migration route. Comparisons of detection rates for chinook caught and released in the Montlake Cut and Lake Union indicated that survival was effectively 100% through that portion of the LWSC between the weeks of May 28 and June 18, 2001 (Table 3-6). These numbers are much higher than that estimated in 2000 (64%), but the latter, lower number may have been associated with mortality caused by a disease outbreak in the LWSC that year. Alternatively, the lower survival estimate for the week of June 25, 2001 is similar to the 2000 estimates, suggesting annual variation exists in the timing of when survival through the LWSC begins to decrease.

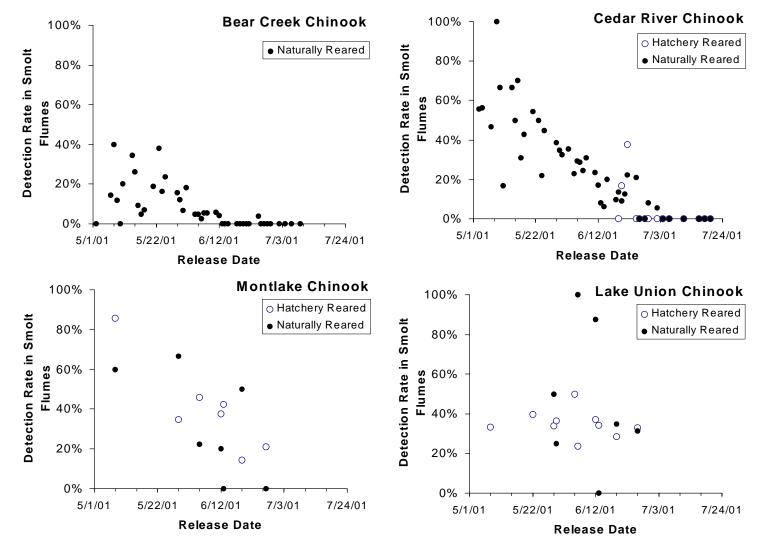


Figure 3-37. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile chinook salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

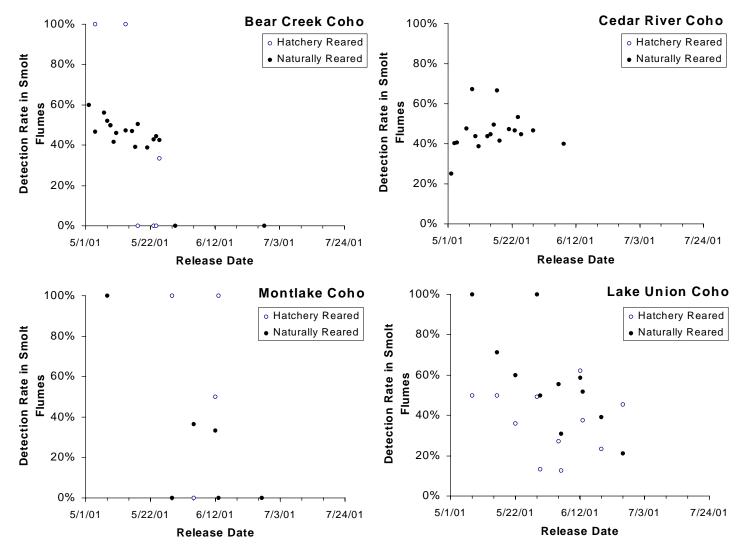


Figure 3-38. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile coho salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

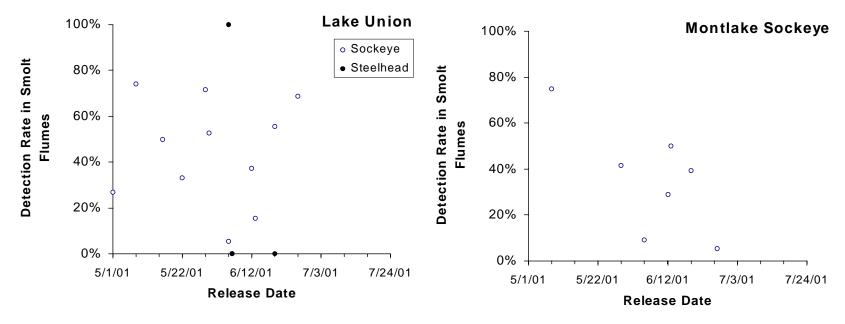


Figure 3-39. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile sockeye salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

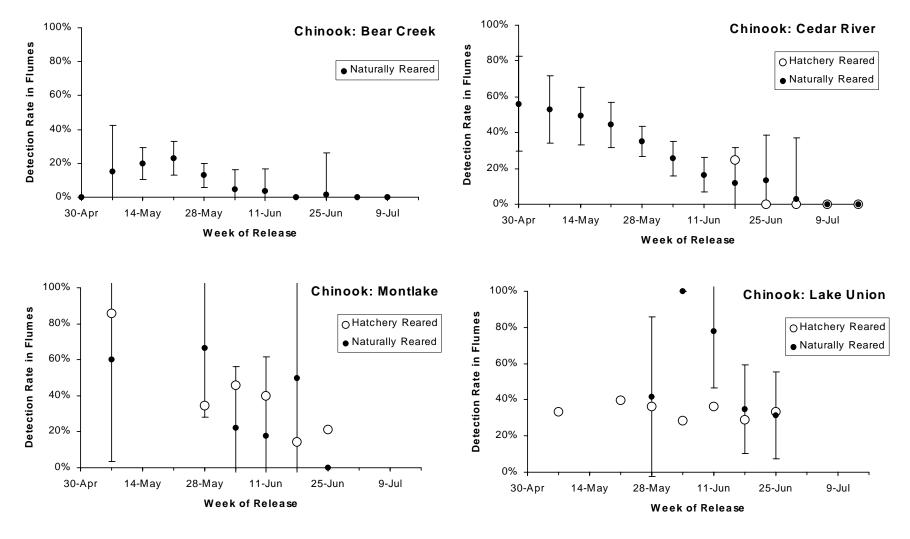


Figure 3-40. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile chinook salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-37 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.

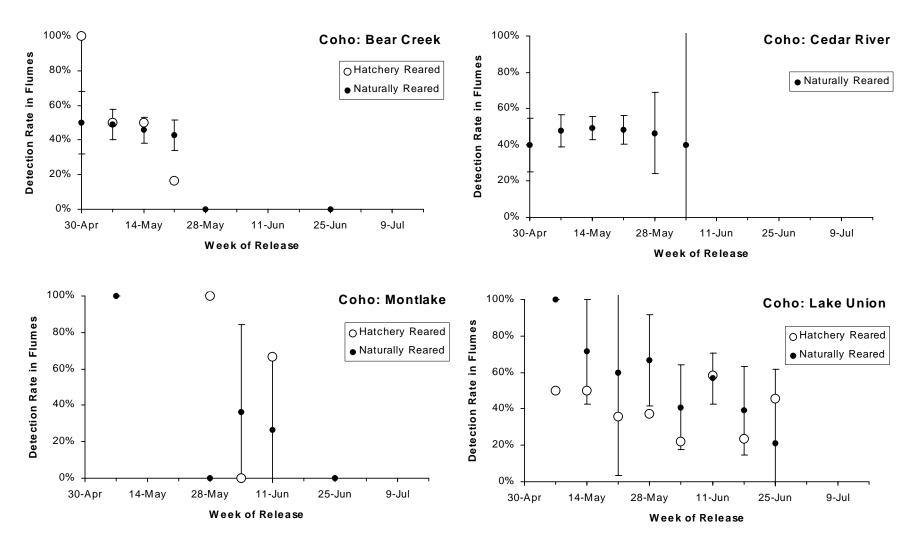


Figure 3-41. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile coho salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-38 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.

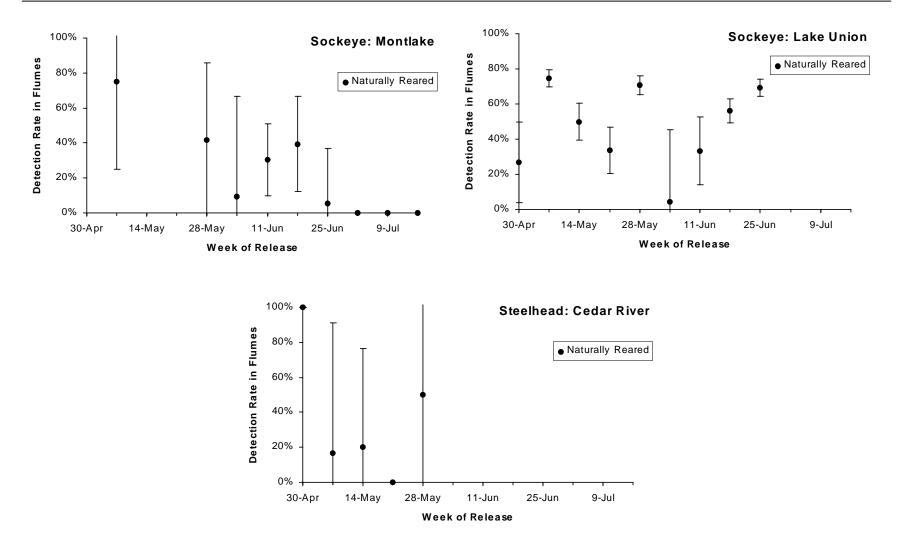


Figure 3-42. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile sockeye salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-39 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.

Table 3-6. Estimated survivals over different segments of the chinook salmon juvenile outmigration route in the Lake Washington system, 2001.

	Chino	ok Release G	roups, By V	Veek of Rele	ase	Estimate	· ·			
	Issaquah Hatchery	Bear Creek	Cedar River	Montlake Cut	Lake Union	Issaquah Hatchery - Bear Creek	Montlake	Cedar River -	Montlake - Fremont Cut	
Comparison 1							53%	100%	100%	
Week of Release		5/14/01	5/21/01	5/28/01	6/4/01					
No. Released		357	142	110	23					
No. in Smolt Flumes		71	63	41	8					
Comparison 2						100%	54%	81%	100%	
Week of Release	5/14/01	5/21/01	5/28/01	6/4/01	6/11/01					
No. Released	4676	320	374	236	160					
No. in Smolt Flumes	1762	74	131	102	62					
Comparison 3							34%	67%	100%	
Week of Release		5/28/01	6/4/01	6/11/01	6/18/01					
No. Released		685	320	255	551					
No. in Smolt Flumes		89	82	98	162					
Comparison 4							27%	94%	53%	
Week of Release		6/4/01	6/11/01	6/18/01	6/25/01					
No. Released		277	360	23	516					
No. in Smolt Flumes		13	59	4	170					

Comparison of detection rates for Issaquah Hatchery fish and chinook caught and released in Bear Creek indicated that survival of the hatchery chinook was also effectively 100% as they migrated to the mouth of Bear Creek.

In contrast, the two tributary chinook stocks appeared to experience a decrease in survival over time during the outmigration period (Table 3-6). Chinook from Bear Creek appeared to experience a steady survival rate as they migrated to the Montlake Cut, of around 53% to 54% during the latter half of May and first week of June. The survival estimates then began to decline each successive week. It is important to note that the magnitude of estimated survival for about the same time period as Comparisons 2 and 3 in Table 3-6 was similar to that determined in 2000 (43%).

Chinook from the Cedar River had a higher survival rate overall compared with chinook from Bear Creek, but exhibited a decreasing trend beginning around the end of May. However, for fish tagged during the second week in June, survival to the Montlake Cut increased again to above the 90% level (Table 3-6). The estimated survivals for the end of May and early June 2001 (81% and 67%) are also similar in magnitude to that determined for Cedar River chinook in 2000 (79%). Hence, the survival estimates for these portions of the migration route appear to be generally consistent between the two years of study.

Post-tagging mortality rates likely influenced the numbers above (see Section 3.1), but assuming they were of similar, small order of magnitude on average would result in the rates effectively canceling out in the calculation of route increment survivals, with a minor effect on the accuracy of the resulting estimate. This may be a reasonable assumption given that only in a few instances did tagging mortality exceed 1%.

Confidence intervals for survival estimates were generally large because of the small numbers of recaptures and the number of tagged fish released in each group (generally 1000 fish or less). A range of variances of the estimated survival of a release group to the Locks were determined by S. Smith of NMFS, assuming *a priori* (in the absence of data) that survival between the Locks and the beach seine sites equaled 0.95. The analyses were conducted for a range of release numbers (1,000 to 10,000 fish), survival magnitudes (0.5 to 0.9), and detection probabilities at the Locks (0.2 to 0.4) and beach seining (0.05 to 0.15). The resulting estimates are presented in Appendix D, and indicate the approximate range of precision that may be expected for the release and recapture numbers presented in Table 3-1, absent other sources of error.

4. DISCUSSION

The results of this study provided important insights supplementing and adding to those obtained in 2000 regarding mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system. In whole, the data indicate that PIT tagging is a useful and important tool for evaluating outmigration characteristics and the effects of the Locks on juvenile salmon, which were primary study objectives. The results further permit evaluation of the relation between Locks operations and downstream passage by salmon smolts, identification of potential changes to operations that may reduce the effects or help conserve water in a benign manner, and identifying future studies that may be designed to obtain more complete information on smolt behavior in the system. These issues are discussed below.

Detection efficiency of the tunnel readers was improved significantly compared with the 2000 study. However, the 2001 study still suffered from the same problem regarding incomplete coverage of all the routes through the Locks, and the resulting data indicate that this may be an important deficiency in evaluating survival through the Locks facilities.

An interesting side observation regarding migration routes through the Lake Washington system is warranted here based on the PIT tagging data. There were no known releases of hatchery chinook in the Cedar River, yet several were captured and tagged at the screw trap beginning on June 19, 2001. It is highly possible that these were Issaquah Hatchery chinook that migrated along the eastern side of Lake Washington, and made a foray into the lower reaches of the Cedar River as they were searching for a passage route (the screw trap was located a short distance upstream of slack water). Assuming a median travel speed of approximately 2.6 km/day (Figure 3-22), and a migration distance of 88 km (determined using a similar technique for deriving Table 3-2), results in an estimated average travel time of 34 days from the hatchery to the Cedar River trap. Since the hatchery fish were released on May 15, this corresponds to an estimated median arrival date of June 18, which is one day before the time that hatchery chinook first starting showing up in the Cedar River samples. This is of the correct order of magnitude to conclude that the hatchery fish in the Cedar River trap most likely originated from the Issaquah Hatchery.

4.1 DOES PIT TAGGING MEET THE STUDY OBJECTIVES?

Based on the results of this and the preceding year studies, PIT tag technology appears to be a viable technique for assessing mortality over different portions of the migration route. This is an

important outcome, even if it is not possible to estimate absolute total mortality over the entire migration route. The results also provide important information regarding migration and passage characteristics, as well as evaluating the effects of the LWSC project on hatchery and naturally-produced chinook and other salmon species. And, although the precision of the survival estimates may be relatively low in this pilot study, similarity between the 2000 and 2001 results suggests that the estimated survivals for the different routes are of the correct order of magnitude. The resulting information thus appears to be extremely useful for evaluating factors influencing survival along different segments of the migration route.

The second study objective was also met. Specifically, PIT tagging was found to be viable for naturally-reared smolts in tributaries to Lake Washington and for smolts migrating through the LWSC. Continued tagging over the outmigration period allows evaluation of temporal variation in survival and migration characteristics.

With respect to the third main study objective, chinook salmon juveniles from the Issaquah Hatchery were observed to be similar to naturally-spawned tributary chinook in terms of migration and passage behavior, and possibly survival to the Locks. An exception was apparent for the calibration test fish, which were held and released under the least "normal" conditions of all the hatchery release groups. The UW Hatchery chinook did not appear to be a reasonable model of naturally reared fish because their outmigration behavior was radically different. However, in lieu of taking tagged hatchery fish to different release locations in Lake Washington Tributaries, and acclimatizing them prior to release, continued tagging of naturally reared fish remains recommended as the most direct means for addressing survival, migration, and passage characteristics.

The large tunnel readers were still operating below the desired minimum detection efficiency of 95%. Flume 4B was operating at an average efficiency of 89% and Flume 5B at 90%. These values are high enough that the adjusted detection numbers give assurance that the trends reported here are realistic. However, they are still sufficiently low that they add a level of uncertainty to total survival estimates. Further structural modifications may be needed.

One potential problem that was not resolved this year and that may have also influenced detection efficiency was "pulsing" of water through the flumes at higher lake levels, and development of standing waves. This was manifest by periodic overtopping of the flume sides near the tunnel reader throats, and a visual pulse in the outfall discharge rate. This pulsing occasionally resulted in the ejection of a fish stick out of the flume before it entered the tunnel

reader. Fish were not observed to have been similarly ejected, and may not have because they appeared to swim near the bottom of the flume as they were drawn into the throat, whereas the sticks were floating on the surface. However, pulsing and overtopping were associated with intense turbulence at the throat entrance, which may have contributed to lower detection efficiency by orienting some fish and fish sticks closer to perpendicular to the long axis of the flume, a sub-optimal orientation. Modification of the flume hydraulics appears necessary.

4.2 MEETING THE ASSUMPTIONS OF PIT TAG BASED SURVIVAL ESTIMATORS

The survival estimates presented in this report must be regarded cautiously. Differential detection rates can provide an indication of survival between two release locations, assuming similar detection probabilities. The validity of this assumption, however, depends on whether the two groups move downstream at about the same time, and are randomly mixed when they arrive at the Locks (Burnham et al. 1987; Iwamoto et al. 1994). The bias in survival estimates that results from not meeting the assumption increases with distance between the two release locations in a reach (Dauble et al. 1993).

In contrast with the 2000 study, the Issaquah Hatchery chinook appeared to have 100% survival as they passed through Lake Sammanish in 2001, as did chinook migrating between the Montlake Cut and the Fremont Cut. Bear Creek chinook appeared to have lower survival to the Montlake Cut than Cedar River chinook. Nevertheless, the segment-specific survival estimates were reasonably consistent for around the same time period in the both 2000 and 2001, suggesting indirectly that the assumption of similar detection probabilities is met once the proportion using the flumes is canceled out in the calculation.

The accuracy and precision of the survival estimates depend on several critical assumptions. Estimates of survival and proportion of tagged fish using the flumes are sensitive to the number of tagged fish recaptured in the beach seine samples. Sampling in 2000 indicated that sampling effort in the inner bay should be on the order of 105 seine samples at each beach site within the bay, with at least 7 daily seine sets needed in each site during the peak chinook outmigration period. This was not feasible in 2001, and additional sampling would be needed in order to increase recapture numbers of PIT tagged fish and minimize the uncertainty about survival estimates. This would also provide more data describing the time of transition between fresh-and saltwater.

It is also possible that the incomplete coverage of passage routes could have had a systematic effect on the survival estimates if different release groups had different mean patterns of migration through the Locks. For example, one group may have migrated predominantly along the south shore where they were more likely to pass through the flumes and be detected, whereas another may have been more likely to have migrated along the north shore and be underrepresented in the PIT tag detection data. We don't know if this is the case or not, but the possibility highlights the importance of sampling the alternate routes for PIT tagged fish as well. Simultaneous releases on both sides of the LWSC using PIT tagged fish are recommended here to evaluate this issue further. The corresponding null hypothesis is that fish released on the north and south sides of the LWSC channel have similar detection rates in the flumes. Such improvements may also increase the accuracy and precision of future survival estimates by providing indirect information on the proportion using the flumes, which could not be addressed adequately in this study because so few tagged fish were captured below the Locks during the peak chinook outmigration period.

A final concern remains regarding release group sample size, which is a statistical, logistical, and financial issue in PIT tagging-based survival studies. The confidence interval estimates depicted in Appendix D indicate that large numbers of fish are required in each tagging release group. There is a break in the curves plotted in Appendix D in terms of the percent change in precision of the estimate with sample size, at about 2,500 to 3,000 fish per group. At higher sample sizes, the incremental reduction in the confidence interval is smaller and changes less rapidly with increasing numbers of tagged fish. At smaller sample sizes, the confidence interval increases at a much greater rate with decreasing numbers of fish tagged. Unfortunately, the two years of study to date indicate that a sample size of 2,500 tagged fish per release group, or per week, is not achievable in Bear Creek and the Cedar River. However, this does not invalidate the overall utility of the data.

4.2.1 Possible Influence of Water Quality on Passage at Locks

Incomplete PIT tag detection coverage at the Locks also has important implications regarding determination of the proportion using the smolt flumes. The data collected in 2001 indicate that the proportion changes with time. A review of available water quality data suggests that the change may be due to changes in water temperature, where surface water temperatures in the LWSC generally reach adverse levels sooner in the outmigration season than near-bottom temperatures. Hence the decrease in detection rates over time could reflect a shift in passage behavior where the outmigrants gradually seek deeper routes through the Locks. This would

most likely occur via the large lock, the sill elevation of which is 20 feet below that of the small lock on the lake side. Water quality data collected by the USACE in the LWSC support this hypothesis. Figure 4-1 shows that water temperatures in 2001 climbed continually during the passage season, and leveled out around the middle of July. In most locations, the near-bottom water temperature was approximately 1-2°C cooler than the surface temperature. Because of this, it is not clear if the data from the Fremont bridge station reflect real conditions or equipment malfunction (Figure 4-1). Water temperatures below the Locks are also much cooler (Figure 4-2), and salt water wedges intruding upstream through the large and small locks would result in cooler, brackish water near the bottom that the smolts may be attracted to as the surface water warms in the LWSC. Water temperatures in the large lock approached 15°C around the beginning of June, and 19°C around the first week in July 2001 (Figure 4-2). These temperatures are of significance because they represent approximate limits to optimal juvenile salmon production and growth, respectively (ODEQ 1995; McCullough 1999). Temperature preference has been correlated with optimal growth temperature, and the general preference of juvenile salmonids appears to be for temperatures that are about 15°C and lower (McCullough 1999). By comparison, detection rates of the tagged Bear Creek and Cedar River chinook and coho smolts began dropping substantially around the end of May, when surface temperatures approached 15°C, and the rates approached zero around the beginning of July 2001 when temperatures approached 19°C (Figure 3-40). This result suggests that use of the smolt flumes may have little benefit for smolt passage as the upper temperature threshold is approached.

4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION

There are several features of lock construction or operation that are suggested by the 2001 PIT tag data to influence downstream passage that are evaluated below. The data further indicate that there are seasonal and diurnal environmental and operational features that result in changes in passage behavior.

The similarity in numbers using both gates when all four flumes are operational suggests that there may not be a nearshore route preference of outmigrants. This possibility was raised in the 2000 study, but it was also suggested at that time that the results might reflect instead attraction flow near the gate entrances (DeVries 2001). In addition to the similar proportions detected in each gate while all four flumes were operational (reported above), a calculation of numbers of smolts per unit volume of water passed through each flume in 2001 also supports this hypothesis. Figure 4-3 depicts the daily passage rates per unit discharge of each species in each flume and tagging location for the study period. Flume 5C generally passed the most chinook and sockeye

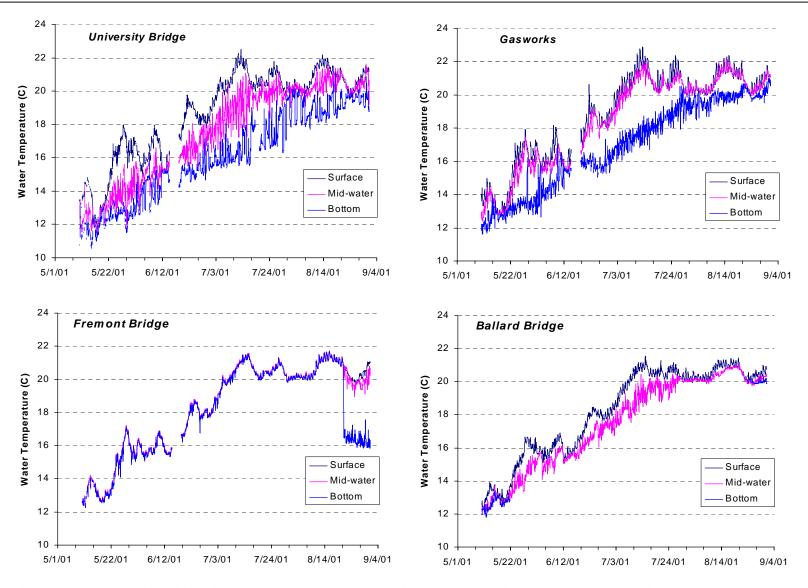


Figure 4-1. Temporal variation in water temperatures measured in the LWSC during the 2001 Lake Washington GI study.

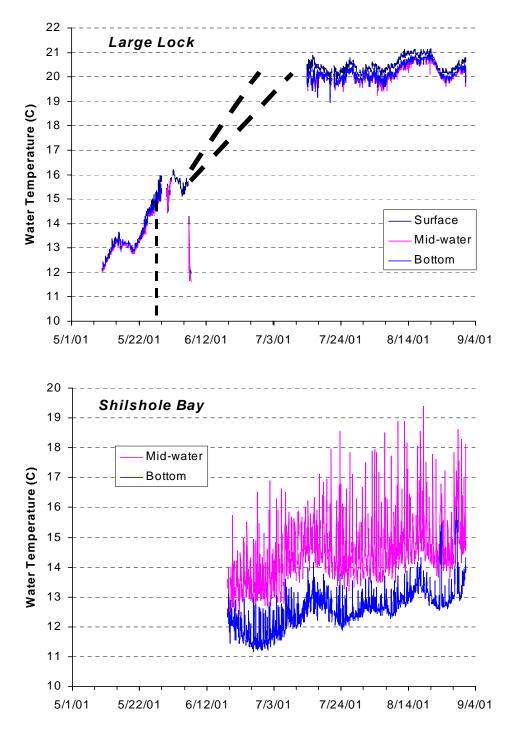


Figure 4-2. Temporal variation in water temperatures measured in the large lock (top) and immediately below the Locks (bottom) during the 2001 Lake Washington GI study. The thick, diagonal dashed lines indicate the likely range of temperatures during a data gap, based on the measurements depicted in Figure 4-1. The vertical dashed line indicates the approximate date when surface water temperatures exceeded the upper preferred temperature for juvenile salmon (15°C; ODEQ 1995; McCullough 1999).

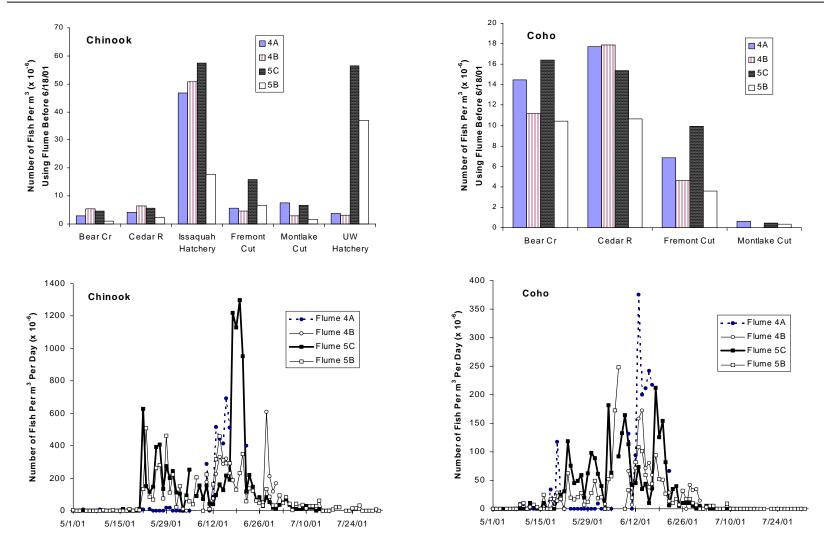
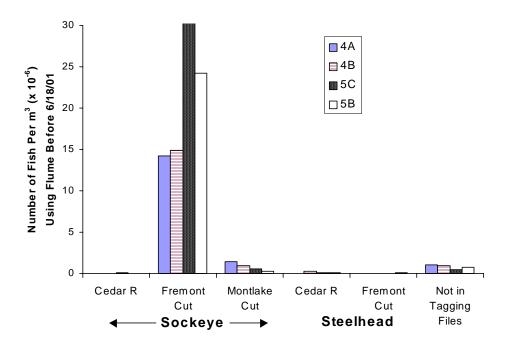


Figure 4-3. Number of PIT tagged salmon passing through each flume normalized to unit discharge, by release location before June 18, 2001 while all four flumes were generally operational (top; see Figure 3-1 for periods of operation), and over the outmigration period (bottom), 2001 Lake Washington GI study.



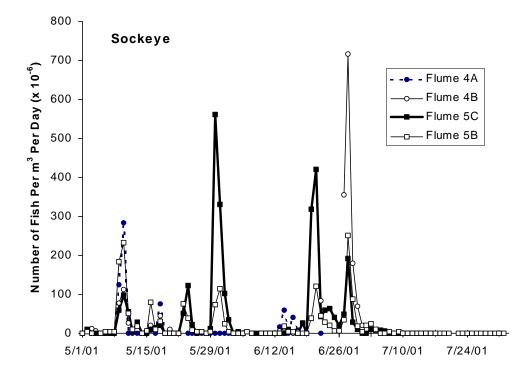


Figure 4-3 cont Number of PIT tagged salmon passing through each flume normalized to unit discharge, by release location before June 18, 2001 while all four flumes were generally operational (top; see Figure 3-1 for periods of operation), and over the outmigration period (bottom), 2001 Lake Washington GI study.

per unit discharge, but this appears to be associated with simultaneous operation of Flume 5B. Results were mixed for coho. Of special note, the UW hatchery chinook appeared to show a strong preference for gate 5 (Figure 4-3). This may have been because Flume 4B was shut down for most of the time that this group passed the Locks, and Flume 4A presented relatively little attraction flow. Hence, while the smaller flumes appear to pass proportionally more fish per unit discharge than the large flumes, their success may be dependent on the total attraction flow rate through the gate. Because the flow fields in the two spill gates appear to be relatively independent of one another, the total flow entering a gate appears to be an important influence on successful use of the smolt flumes. This is consistent with other data suggesting increased passage rates with increased spill through gate 2 (BioSonics, Inc. 2001).

4.3.1 Influence on Juveniles Located Below the Locks

As in 2000, the tunnel detector and large lock purse seining data from 2001 indicate that some fish recycled through the Locks. It is unknown whether this was because (i) fish were entrained during lock openings and became disoriented, (ii) some fish that passed through the flumes were not completely smolt-ready and thus actively avoided more saline water by swimming upstream through the Locks in the less saline lens, or (iii) fish were swimming about in pseudo-random movements that were directed on average in the upstream direction.

The influence of entrainment into the large lock is difficult to evaluate because of the physics involved. As the lower gate is opened, a saline wedge intrudes near the bottom into the large lock chamber, resulting in downstream displacement of a surface lens of the relatively wellmixed, but less saline water initially present in the lock chamber (Lingel 1997). If juvenile salmonids are entrained physically from downstream, they would thus have to be present primarily within the deeper, more saline water that moves upstream. Fish present nearer the surface would tend to be moved in the downstream direction because of the density currents (Lingel 1997). Alternatively, if juveniles were seeking fresher water, they would initially have to swim upstream against the surface discharge of less saline water. Once inside the chamber, the same process is repeated when the upper gate is opened. Hence, if fish are indeed entrained in the upstream direction to above the Locks, they would have to be consistently within the deeper parts of the water column. Underwater video data and visual observations suggest that salmonid smolts are surface oriented in the vicinity of the Locks structures, while acoustic data show that surface-oriented aggregations, when entrained through filling culverts into the large lock chamber, resume their surface orientation within minutes (J. Dawson, BioSonics Inc., personal communication). These observations are consistent with the findings of Schreck et al.

(2000), who determined that fish in the Columbia River estuary held within the upper 4 m of the water column, in fresher water as they made the transition to saltwater. This type of smolt behavior may reduce the likelihood of physical entrainment in the upstream direction during gate opening operations. In addition, Johnson et al. (2001) determined that fish near the entrance to the large lock filling culvert entrance were distributed in two distinct groups, one near the bottom and one near the surface. Although species in each group were not determined, the composition likely reflects vertical salinity differences with downstream migrant smolts remaining in the upper freshwater layer when the upper gates are opened.

Smolts that may be entrained upstream in the saltwater wedge and re-exposed to lake water may be able to similarly withstand the transition (particularly chum and coho salmon; Clarke and Hirano 1995), but the physiological costs and resulting stress levels have not been determined in the case of the Locks. This would need to be addressed, for example, if it were determined that saltwater-acclimated smolts were entrained upstream in the deeper, more saline layer.

The trend depicted in Figure 3-33 of shorter recycling interval as the spring outmigration season progresses suggests that an avoidance of more saline water may be plausible in the case of some fish. These fish would have to either initially swim upstream in the surface layer outflow when the gates are opened, or have a non-random tendency to swim upstream into the lock chamber when the density currents have subsided, prior to closing of the gate. We do not know the answer to this presently.

Water quality profile data collected below the Locks by C. Simenstad and W. Couch of the University of Washington in 1999, and by D. Houck of King County/Metro in 2000 and 2001 indicate that there is a low-salinity lens in roughly the upper 1 to 3 meters of the water surface that is less than 20 ppt in concentration. This lens sometimes extends out to the railroad bridge and beyond depending on discharge at the Locks and tide. Table 3-5 suggests that a rapid osmotic transition had occurred in many of the juveniles captured in the beach seine samples in the inner bay area, where salinities nearer the surface are on the order of 15-20 ppt during the spring outflow months. Juvenile and fry chinook salmon are capable of sudden transitions from freshwater to water with salinities as high as 16 to 20 ppt without apparent adverse survival effects (Macdonald et al. 1988; Healey 1991; Clarke and Hirano 1995; Kreeger 1995). However, tolerance of even 30 ppt has been noted to not be an adequate criterion for identifying smolts (Clarke and Hirano 1995), and thus it is possible that the relatively quick transition may still be stressful (Macdonald et al. 1988). The possibility also exists for increased delayed mortality in saltwater after the transition, associated with scale loss when water temperatures in the LWSC

increase to stressful levels during the outmigration season (Clarke and Shelbourne 1985). Blood chemistry sampling of PIT tagged fish passing through the flumes and caught in the beach seine samples would provide more direct evidence of physiological stress and smolt readiness. In any case, the PIT tag data suggest that the downstream migrants spend relatively little time in the lower salinity lens below the Locks before making the transition to higher salinity water. They may thus spend relatively little time in an 'estuarine' setting with salinities below 10 ppt, unless they first spend some time in the saltwater wedge above the Locks. Available hydroacoustic data indicate that some smolts are distributed within this more saline zone above the Locks (Johnson et al. 2001; P. Johnson, pers. comm.). It is thus possible that a subset of the total outmigrant population acclimatizes to high salinity water before passing the Locks.

What also remains unknown is whether fish that make the transition are more susceptible to avian or other forms of predation during that short period while they are confined to the relatively small freshwater area below the Locks. Macdonald et al. (1988) noted this to be a problem for fish that were released directly in water with salinity greater than 11 ppt, suggesting a similar problem may exist for juveniles passing the Locks. This is the subject of work conducted by the MIT (Footen 2000).

4.3.2 Influence on Juveniles Located Above the Locks

Another behavioral influence of large and small lock operations is suggested by the PIT tag data regarding the movement of juveniles located above the Locks. As in 2000, the PIT tag data for 2001 suggest that filling operations of the small and large locks may influence passage timing through the flumes through transient changes in velocity patterns that occur in the forebay area. Responses by smolts to temporal and spatial changes in velocity have been noted elsewhere (e.g., in the Stanislaus River by Cramer and Demko 1993; in the Columbia River by Johnson et al. 2000). Juveniles may be induced to swim more actively in the forebay in response to unsteady flows when local currents increase temporarily while the large or small locks are filling. Increased swimming activity may increase the probability that outmigrants encounter the smolt flume entrances, with increased probability of passage.

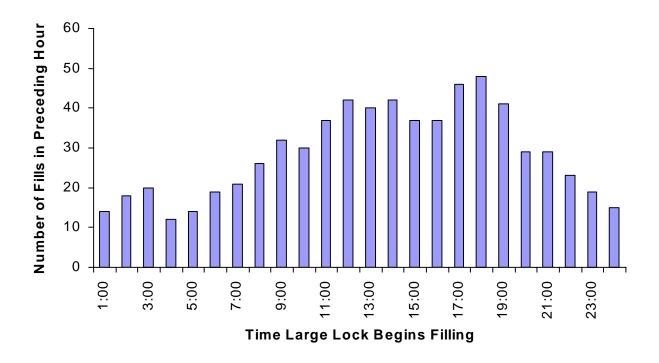
4.3.3 Suggested Changes in Operations

Only two changes to flume operations are suggested by the data presently. Because nearly all of the PIT tagged fish passed through during daylight hours in both 2000 and 2001, the flumes could be shut off at night to conserve water so that they can be open to passage for a longer

period during the smolt migration season, possibly through the end of July. The PIT tag data suggest that more than 90% of the tagged fish passed through the flumes between daybreak and dusk in May and June. A similar trend was noted in 2000, through both the flumes (DeVries 2001) and spill gate #2 (BioSonics, Inc. 2001). The reason for this is unknown, but may be related to the frequency that the small and large locks are filled. Figures 3-35 and 3-36 suggest that a passage response exists with respect to lock filling. Figure 4-4 indicates that the frequency distributions for small lock filling times and smolt flume passage times are relatively similar (cf. Figure 3-29). The greater proportion of passage during the morning hours compared with the afternoon could reflect fish that arrive overnight and are waiting for passage cues. The large lock appears to have had a smaller influence than the small lock as its fill time distribution is more uniform (Figure 4-4). Since small and large lock fill times reflect use patterns that are unlikely to change, shutting the flumes down at night would help address water conservation needs for improving smolt passage at the Locks, a significant problem identified by USACE (1998).

A potential, adverse side effect that may need to be investigated, however, is related to the reduction in freshwater discharge and the corresponding effect on the spatial extent of the low salinity lens below the Locks during the night. Preliminary salinity data collected by King County in the spillway tailrace area indicate that the freshwater lens there may be reduced considerably in surface area and depth when the flumes are not operating, depending on tide. This could make the smolts more susceptible to piscine or avian predation if it is determined that they remain in the immediate vicinity of the tailrace area within the freshwater lens for an extended period (which seems unlikely based on the salt water recapture data), and are thus concentrated within a smaller area while they are making the transition to saltwater. This depends, of course, on whether significant predation occurs at night (night lighting in the area could conceivably facilitate this). In addition, avian predation has generally been observed immediately below the Locks during low tide, which is the time with the greatest freshwater lens (D. Houck, pers. comm.). It is not clear if this is thus an issue and is raised here strictly as a hypothesis. At this time, there is insufficient evidence to suggest the need for night spill in this context.

The second change suggested by the 2001 data is that the flumes could potentially be shut down for the season when surface water temperatures in the LWSC in the vicinity of the Locks reach 19°C. The route of passage appears to shift to deeper alternatives, with few fish using the flumes after that temperature threshold is reached.



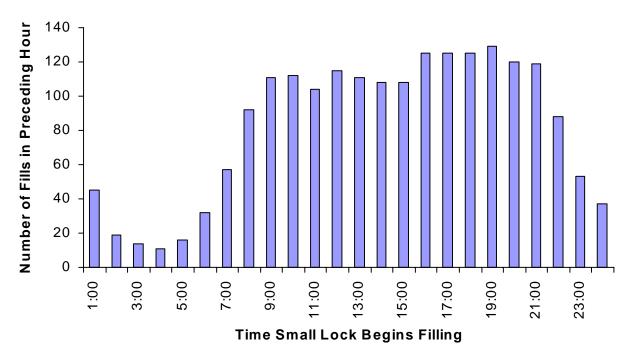


Figure 4-4. Diurnal variation in times at which the large (top) and small (bottom) Locks began to fill during the PIT tag study period of May 1 through July 14, 2001 Lake Washington GI study.

Other than possibly increasing attraction flows to the entrance of the smolt flumes (which could also increase the area of the mixing zone in the spillway tailrace), no changes to lock operations were suggested by the PIT tag data at this time. However, because there appears to be an influence of lock filling operations on smolt passage through the flumes, a possible future investigation would involve assessing systems that guide smolts to the flumes when the Locks are filling through their culvert intakes, and the effects of attraction flows. Recent work on the Columbia River system should provide an indication of whether appropriate structural measures would be technically feasible. The investigation should at the same time determine and compare the proportions of fish entering the large and small locks when the gates are opened to the numbers passing through the smolt flumes to determine whether guidance measures in particular would be expected to improve flume passage numbers measurably and economically.

4.4 FUTURE STUDY RECOMMENDATIONS

The following possible changes to study design are suggested on the basis of the data collected this year, and accompanying justifications are given:

- The vibration problem associated with the tunnel readers needs to be corrected additionally for the large flumes (4B and 5B). Detection efficiencies improved markedly over those experienced in 2000 as a result of the structural modifications applied in 2001, but it is important to continue working toward increasing the detection efficiency to above 95% as much as possible to reduce this source of variation to a negligible level. One possibility is to experiment with hydraulics within the flumes to reduce pulsing and smooth out the water surface within the tunnel readers and the flume flow lines.
- Calibration testing should continue with both tagged fish and the "fish sticks." Although the sticks perform well, it was determined during the 2001 study that the 0° sticks may slightly over-estimate detection efficiency for live fish. The 45° sticks appear to be more realistic, but may also slightly underestimate efficiency. Additional data are needed to further refine the calibration relation between the respective detection efficiencies.
- Fish should be tagged again in similar numbers at the Issaquah Hatchery and released from there directly into the stream to evaluate the high survival through Lake Sammamish suggested by the 2001 data. Tagging should also be performed at the Bear Creek and Cedar River screw traps between early May and early July to duplicate the results of this year's study regarding temporal variation in the proportion using the smolt flumes.

- If possible, purse seining and PIT tagging should be continued in Lake Union and in the
 vicinity of the Montlake Cut, to evaluate survival increments over different segments of
 the migration route. In contrast to 2000 when there were disease problems, the 2001 data
 suggest negligible mortality occurred in the LWSC. Further study would be useful for
 evaluating factors of decline in the LWSC.
- Beach seining for PIT tagged fish should focus on the inner bay and railroad bridge area, and not in the outer bay area, and be conducted more frequently to increase the catch numbers of PIT tagged fish. This is a critical component of the study, particularly with respect to estimating the proportion of fish using the flumes compared with other routes. In order to increase sampling effort and capture rate in the inner bay/railroad bridge area, purse seining should also be evaluated for feasibility and effectiveness. However, there is a risk that an insufficient number of recoveries will be made to determine the proportion using the flumes to a desired level of precision, and that more intensive sampling during the peak outmigration period may result in harming too many ESA-listed juvenile chinook salmon. A possible resolution to this problem would be to use an open-ended tow net fitted with a submersible PIT tag detector, where fish would be concentrated and pass through the detector with much lower potential for adverse effects. The feasibility of this would depend on the general absence of obstructions and "snags," and the robustness of the detector in the saltwater environment.
- If beach seining is continued below the Locks, control groups of PIT tagged fish should be released at the downstream base of the spillway dam, per study designs discussed by Burnham et al. (1987). This would result in better estimates of the proportion of fish using the flumes (P_{SF}) and survival. These groups are required because beach seine capture efficiency is also unknown and needs to be estimated in order to estimate the other parameters. However, substantially increased capture effort would be required below the Locks than occurred in 2000, to increase the recapture sample size. Figure 4-5 depicts the estimated sample size of PIT tag recaptures below the docks associated with a range of precision about the estimate of P_{SF}. The numbers and curve trend in the figure are generally representative for a range of release group sizes, survival to the Locks, and proportion using the flumes. Although the capture efficiency is unknown, the required sampling effort can be determined indirectly using the graph by noting that no more than 2 fish from a weekly release group (e.g., Bear Creek, Lake Union; not including calibration fish) were caught during the June 18-19 and 21-22 "blitz" sampling in 2001. Based on the typical range of weekly release numbers during the peak chinook outmigration (~100-500/week/location), about 40 PIT tagged fish would need to be caught from a given weekly release to know with about 95% confidence that the proportion using the flumes is $X\% \ \forall \ 15\%$ (absolute value). This corresponds to increasing the sampling effort up to 20-fold to get 40 tagged fish from a given weekly

release group. This estimate differs from the effort increase suggested in the first year's report (DeVries 2001), which was based in part on lumping the entire passage season together. In addition, sampling would need to account for the apparent seasonal change in proportion using the flumes in order to evaluate survivals.

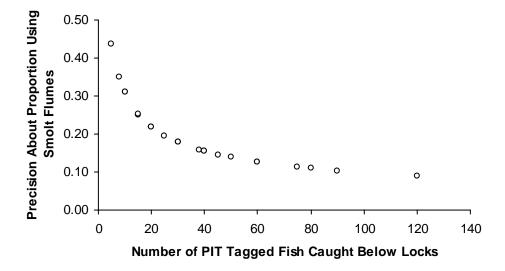


Figure 4-5. Variation in the approximate precision about the estimated proportion using the smolt flumes at the Locks, with numbers of PIT tagged fish recaptured by beach seining in Shilshole Bay.

- Purse seining could be conducted in the large lock and small lock to determine the proportion of PIT tagged fish passing through each, as well as provide better information on recycling patterns through the Locks. Because less water is used to fill the small lock than the large lock, it is possible that relatively less effort could be expended in the former. However, the data would only re-confirm that recycling takes place, which appears to be determined more thoroughly based on the tunnel reader detections. Much greater sampling effort would likely be needed if the data from the two locks were to be used to determine the proportion of tagged fish using that route.
- Sampling could also be conducted periodically in the fish ladder for PIT tagged fish. It is
 possible to construct a downstream migrant trap from which juveniles can be removed
 and scanned for PIT tags, although such a trap is time consuming to operate (D. Seiler,
 pers. comm.) and may interfere with upstream adult migration (E. Warner, pers. comm.).
 Planned construction of a PIT tag detector for returning adults would also be useful for
 monitoring smolts in subsequent years.

- Further tagging of UW hatchery chinook is not recommended because their migration and passage behaviors are so different from the other study groups.
- Fish should be held at the Metro Laboratory in 2002 for two purposes: (1) calibration testing, and (2) for release in the LWSC to evaluate shoreline affinity and effects on the proportion using the smolt flumes. Equal number groups should be released on the north and south shores, at different locations in the LWSC. It would be preferable to do this during the third week in June when the peak chinook outmigration is occurring. However, it will be necessary to hold the fish at the Lab at temperatures that are equal to or near the temperatures in the LWSC so that the fish are not thermally stressed upon release. Therefore, the fish should be held as long as possible, and released well before temperatures reach 19°C (e.g., at 17°C, which is the midpoint between the two thresholds evaluated here), and before disease or stress become a significant problem (but as close to the middle of June as possible).
- The blood of subsamples of PIT tagged fish passing through the flumes and caught in the beach seining should be tested for stress and signs of osmotic change or smolt readiness. This information is important for evaluating the effects of the Locks with respect to the relatively sudden transition to saltwater. Both smolt readiness (e.g., gill ATP-ase, sodium levels) and stress (e.g., plasma cortisol) measures would be required to determine if the fish caught in the beach seine samples were experiencing stress from rapid transition to saltwater because they were not completely ready to do.

5. REFERENCES

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